STATISTICAL COMPUTING FINAL PROJECT

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2022-12-13

MODEL 1: BAGGING MODEL

Model 1 used these three classification ensembles models: * Bagging Model * Gradient Boosting Model * Stacking Model

Libraries Needed for Pre-processing

```
library(readr)
library(dplyr)
library(ggplot2) # for plotting
library(caret) # pre-processing and modeling
library(corrplot)
library(fastDummies) # for creating dummy variables
pacman::p_load(tidyverse)
pacman::p_load(bestNormalize)
```

DATA ACQUISITION AND PRE-PROCESSING

Dataset

radiomics_completedata.csv data was used for this project. The data has a 431 variables and 197 observations including *Failure.binary* as our target/response/outcome variable with its 430 predictors/features/independent variables. *Failure.binary* is a binary variable with 1 and 0 as its values.

```
radiomics = read.csv("radiomics_completedata.csv")
head(radiomics)
```

```
##   Institution Failure.binary  Failure Entropy_cooc.W.ADC GLNU_align.H.PET
## 1           A              0 49.30000           12.85352         46.25635
## 2           A              1 12.56667           12.21115         27.45454
## 3           A              0 79.80000           12.75682         90.19570
## 4           A              1 17.86667           13.46730        325.64333
## 5           A              0 39.56667           12.63733         89.57904
## 6           A              1  4.76667           13.16159        101.71345
##   Min_hist.PET Max_hist.PET Mean_hist.PET Variance_hist.PET
## 1     6.249117    17.825541      9.783773          6.814365
## 2    11.005214    26.469077     15.426640         12.932074
## 3     2.777718     6.877486      4.295330          0.923425
## 4     6.296588    22.029843     10.334779          6.649795
## 5     3.583846     7.922501      4.454175          0.572094
## 6     2.597947     6.206142      3.769041          0.615282
##   Standard_Deviation_hist.PET Skewness_hist.PET Kurtosis_hist.PET
## 1                    2.612479          0.688533         -0.339727
## 2                    3.598298          0.789526         -0.319613
```

```
## 3                   0.962163          0.248637         -0.944246
## 4                   2.580759          0.832011          0.855861
## 5                   0.757225          1.574845          3.250288
## 6                   0.785315          0.610611         -0.090239
##   Energy_hist.PET Entropy_hist.PET AUC_hist.PET H_suv.PET Volume.PET
## 1        0.005095         9.629587     0.506553  1.123930  13751.970
## 2        0.006297         8.072951     0.507519  1.927281   9327.705
## 3        0.005015         9.669316     0.503300  0.410573  26624.003
## 4        0.003289        10.574730     0.544274  0.919612  51058.073
## 5        0.008066         7.621834     0.543922  0.306344  29414.553
## 6        0.005237        10.589120     0.507322  0.388752  14240.032
##   X3D_surface.PET ratio_3ds_vol.PET ratio_3ds_vol_norm.PET irregularity.PET
## 1        5622.519          3.214263               15.91400         2.212137
## 2        8356.832          4.848032               21.09429         2.348324
## 3       16832.003          3.163721               19.52154         2.121251
## 4       29100.294          2.027384               20.12864         1.859572
## 5        7769.379          4.815431               21.01721         2.219725
## 6        9563.905          3.699578               18.53249         2.136984
##   tumor_length.PET Compactness_v1.PET Compactness_v2.PET
## 1         44.04796           0.003366           0.002778
## 2         39.39796           0.003078           0.002637
## 3         50.91422           0.003145           0.002664
## 4         76.23900           0.003118           0.002653
## 5         36.93490           0.003081           0.002638
## 6         46.00253           0.003195           0.002687
##   Spherical_disproportion.PET Sphericity.PET Asphericity.PET Center_of_mass.PET
## 1                    15.91400       0.065378        14.91400           0.811086
## 2                    21.09429       0.049942        20.09429           0.587732
## 3                    19.52154       0.053762        18.52154           0.393189
## 4                    20.12864       0.052217        19.12864           0.866799
## 5                    21.01721       0.050116        20.01721           0.525997
## 6                    18.53249       0.056497        17.53249           0.308017
##   Max_3D_diam.PET Major_axis_length.PET Minor_axis_length.PET
## 1        44.04796              34.60475              25.88546
## 2        39.39796              35.13100              27.30539
## 3        50.91422              48.12896              30.37293
## 4        76.23900              64.12797              54.46594
## 5        36.93490              35.99413              23.84296
## 6        46.00253              42.95117              31.60120
##   Least_axis_length.PET Elongation.PET Flatness.PET Max_cooc.L.PET
## 1              24.98484       0.750543     0.724516       0.005020
## 2              21.15130       0.779759     0.604571       0.008190
## 3              27.52209       0.633585     0.574348       0.005033
## 4              51.56490       0.851856     0.806616       0.005971
## 5              21.38912       0.664919     0.596741       0.007553
## 6              15.99647       0.738262     0.374927       0.005396
##   Average_cooc.L.PET Variance_cooc.L.PET Entropy_cooc.L.PET DAVE_cooc.L.PET
## 1           22.87750            205.6627           10.688721       11.857838
## 2           21.90654            226.6299           10.291026       13.993568
## 3           27.25065            208.9461           10.878250       12.281559
## 4           17.81061            102.6657           10.238635        7.473982
## 5           15.35938            142.2193            9.829042       10.237690
## 6           23.34637            181.6257           10.702694       11.660805
##   DVAR_cooc.L.PET DENT_cooc.L.PET SAVE_cooc.L.PET SVAR_cooc.L.PET
```

```
## 1        84.21646        4.997454        45.75246        587.8808
## 2       129.35103        5.205762        43.81055        581.4143
## 3        85.30680        5.004455        54.49878        599.6980
## 4        43.94774        4.379716        35.61869        310.8875
## 5        79.40248        4.799453        30.71623        384.7110
## 6        87.31571        4.964671        46.69022        503.2667
##   SENT_cooc.L.PET ASM_cooc.L.PET Contrast_cooc.L.PET Dissimilarity_cooc.L.PET
## 1        6.530649       0.003302           234.76478                11.857838
## 2        6.489125       0.003596           325.10017                13.993568
## 3        6.587702       0.003198           236.08136                12.281559
## 4        6.108770       0.003680            99.77033                 7.473982
## 5        6.049095       0.004001           184.16098                10.237690
## 6        6.460137       0.003268           223.23109                11.660805
##   Inv_diff_cooc.L.PET Inv_diff_norm_cooc.L.PET IDM_cooc.L.PET
## 1            0.165784                 0.858670       0.088949
## 2            0.156018                 0.839093       0.085385
## 3            0.154252                 0.852986       0.079027
## 4            0.228938                 0.904866       0.141631
## 5            0.188717                 0.875632       0.108336
## 6            0.166582                 0.860102       0.090157
##   IDM_norm_cooc.L.PET Inv_var_cooc.L.PET Correlation_cooc.L.PET
## 1            0.953919           0.091308               0.431777
## 2            0.937653           0.087501               0.285278
## 3            0.952616           0.084629               0.437596
## 4            0.980381           0.149832               0.516631
## 5            0.963872           0.114365               0.355073
## 6            0.955880           0.093295               0.387992
##   Autocorrelation_cooc.L.PET Tendency_cooc.L.PET Shade_cooc.L.PET
## 1                   611.5456            587.8808        6860.4448
## 2                   543.8667            581.4143        4691.7137
## 3                   833.3669            599.6980         403.0883
## 4                   369.9095            310.8875        3805.6356
## 5                   285.9728            384.7110        9785.4495
## 6                   614.9464            503.2667        4106.7640
##   Prominence_cooc.L.PET IC1_.L.PET IC2_.L.PET Coarseness_vdif_.L.PET
## 1              869822.0  -0.083966   0.789572                0.014320
## 2              803734.5  -0.096731   0.814047                0.014196
## 3              800129.8  -0.072366   0.758160                0.016269
## 4              345452.5  -0.050269   0.655209                0.004936
## 5              743501.3  -0.070677   0.727840                0.017239
## 6              708597.7  -0.073872   0.759220                0.016045
##   Contrast_vdif_.L.PET Busyness_vdif_.L.PET Complexity_vdif_.L.PET
## 1             1.021460             0.087378               17053.35
## 2             1.510199             0.080209               21289.19
## 3             1.014169             0.057518               15199.89
## 4             0.306364             0.392674               10762.05
## 5             0.854170             0.081956               16796.63
## 6             0.895212             0.069338               15170.83
##   Strength_vdif_.L.PET SRE_align.L.PET LRE_align.L.PET GLNU_align.L.PET
## 1             27.40494        0.986583        1.070671        10.162131
## 2             35.76496        0.989835        1.057129         8.416510
## 3             24.45341        0.989308        1.057095         9.117958
## 4              5.55092        0.973462        1.129413        94.565775
## 5             57.03783        0.986186        1.069172        10.574675
```

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## 6             26.08534        0.985853        1.070890        10.057347
##   RLNU_align.L.PET RP_align.L.PET LGRE_align.L.PET HGRE_align.L.PET
## 1         383.8912       0.981089         0.063695         590.1484
## 2         263.3486       0.985313         0.065825         560.1103
## 3         394.6779       0.984963         0.039224         781.3663
## 4        2941.3190       0.963661         0.048051         386.6793
## 5         262.4745       0.981101         0.091713         295.6003
## 6         397.9059       0.980630         0.048144         627.3399
##   LGSRE_align.L.PET HGSRE_align.L.PET LGHRE_align.L.PET HGLRE_align.L.PET
## 1          0.062491          580.5855          0.068738          631.5734
## 2          0.064212          554.5346          0.072438          583.5148
## 3          0.038778          768.0350          0.041011          836.1597
## 4          0.046564          376.9558          0.054360          428.3121
## 5          0.090222          292.3243          0.097821          308.7154
## 6          0.047408          618.2607          0.051089          665.2563
##   GLNU_norm_align.L.PET RLNU_norm_align.L.PET GLVAR_align.L.PET
## 1              0.027914              0.961445          201.5094
## 2              0.033437              0.969710          214.6379
## 3              0.024834              0.968128          216.6109
## 4              0.032318              0.928789          107.6866
## 5              0.041113              0.960224          121.3562
## 6              0.026718              0.959459          187.2442
##   RLVAR_align.L.PET Entropy_align.L.PET SZSE.L.PET LZSE.L.PET LGLZE.L.PET
## 1          0.025908            5.586143   0.926936   1.384001    0.062262
## 2          0.021453            5.385714   0.961338   1.244838    0.064793
## 3          0.020843            5.702830   0.974475   1.114749    0.040452
## 4          0.046375            5.480351   0.905696   1.617562    0.047964
## 5          0.024509            5.053054   0.966013   1.148597    0.093268
## 6          0.025153            5.622598   0.936782   1.322943    0.046110
##   HGLZE.L.PET SZLGE.L.PET SZHGE.L.PET LZLGE.L.PET LZHGE.L.PET GLNU_area.L.PET
## 1    592.5775    0.056127    553.5787    0.089951    831.7709        9.166018
## 2    566.7718    0.060570    546.1829    0.086532    650.3679        7.817915
## 3    769.6933    0.040391    735.9377    0.040694    904.7157        8.877842
## 4    393.5484    0.043346    360.6300    0.076789    591.1260       83.352565
## 5    300.9426    0.091138    295.8022    0.101787    321.5044       10.245976
## 6    617.0878    0.041385    567.5274    0.065899    836.6098        9.390127
##   ZSNU.L.PET ZSP.L.PET GLNU_norm.L.PET ZSNU_norm.L.PET GLVAR_area.L.PET
## 1   301.1987  0.899841        0.027499        0.823228         201.7881
## 2   233.4102  0.941158        0.032589        0.900252         213.9100
## 3   372.1247  0.966472        0.024663        0.930516         216.4466
## 4  2206.3053  0.860538        0.031941        0.781042         109.9100
## 5   242.2684  0.956101        0.040895        0.909893         123.6639
## 6   325.9069  0.913118        0.026787        0.844660         184.6198
##   ZSVAR.L.PET Entropy_area.L.PET Max_cooc.H.PET Average_cooc.H.PET
## 1    0.142022           5.886187       0.031232           39.87474
## 2    0.109793           5.546278       0.043568           39.22729
## 3    0.038537           5.775912       0.169447           44.90994
## 4    0.259194           5.901957       0.040212           38.15816
## 5    0.048849           5.156114       0.423535           49.45276
## 6    0.116919           5.851581       0.217884           46.26425
##   Variance_cooc.H.PET Entropy_cooc.H.PET DAVE_cooc.H.PET DVAR_cooc.H.PET
## 1           255.25108           6.344137       13.397288        131.6433
## 2           259.22064           7.168339       14.938851        146.5065
## 3           226.94291           3.662030       11.817845        143.8888
```

```
## 4           276.46636           6.205163       12.489582        129.5153
## 5            65.47745           2.835302        6.261891         56.9727
## 6           174.57711           3.122212       10.059360        134.1508
##   DENT_cooc.H.PET SAVE_cooc.H.PET SVAR_cooc.H.PET SENT_cooc.H.PET
## 1        4.528843        79.74696        769.9364        5.285948
## 2        2.880112        75.45206        667.2773        5.693972
## 3        4.354173        89.81735        824.2760        3.057425
## 4        4.257568        76.31379        820.4186        5.186241
## 5        3.891832        98.90299        765.7524        2.360339
## 6        1.916625        92.52596        463.0127        2.599031
##   ASM_cooc.H.PET Contrast_cooc.H.PET Dissimilarity_cooc.H.PET
## 1       0.017558            311.0628                13.397288
## 2       0.012079            369.6002                14.938851
## 3       0.096088            283.4905                11.817845
## 4       0.020168            285.4418                12.489582
## 5       0.233933             96.1523                 6.261891
## 6       0.146959            235.2907                10.059360
##   Inv_diff_cooc.H.PET Inv_diff_norm_cooc.H.PET IDM_cooc.H.PET
## 1            0.240428                0.846191       0.181276
## 2            0.198536                0.831014       0.137656
## 3            0.439712                0.866805       0.405377
## 4            0.279879                0.856139       0.224079
## 5            0.576561                0.923498       0.543300
## 6            0.516123                0.886644       0.485744
##   IDM_norm_cooc.H.PET Inv_var_cooc_.H.PET Correlation_cooc.H.PET
## 1            0.940222            0.030684               0.393202
## 2            0.929828            0.032006               0.289621
## 3            0.944553            0.011773               0.377943
## 4            0.945253            0.032706               0.486297
## 5            0.980482            0.021087               0.268281
## 6            0.953100            0.009811               0.328640
##   Autocorrelation_cooc.H.PET Tendency_cooc.H.PET Shade_cooc.H.PET
## 1                   1689.514            709.9364        -2209.927
## 2                   1613.004            667.2773        -4195.799
## 3                   2101.874            624.2760        -4303.802
## 4                   1589.599            820.4186        -5395.462
## 5                   2462.728            165.7524         1099.232
## 6                   2197.079            463.0127        -2285.992
##   Prominence_cooc.H.PET IC1_d.H.PET IC2_d.H.PET Coarseness_vdif.H.PET
## 1            1028531.31   -0.043805    0.512217              0.004319
## 2             957339.84   -0.023569    0.418010              0.005180
## 3             729696.02   -0.063791    0.473698              0.003375
## 4            1434052.83   -0.069422    0.611279              0.002825
## 5              55971.88   -0.044636    0.360145              0.003902
## 6             381561.77   -0.056410    0.417972              0.003199
##   Contrast_vdif.H.PET Busyness_vdif.H.PET Complexity_vdif.H.PET
## 1            49.10863            0.141647              25517.13
## 2            28.26579            0.103194              28339.01
## 3           220.66779            0.236919              24028.42
## 4            40.72831            0.833266              23437.94
## 5            32.04753            0.124684              15279.35
## 6           271.03091            0.279836              22773.21
##   Strength_vdif.H.PET SRE_align.H.PET LRE_align.H.PET RLNU_align.H.PET
## 1            19.64713        0.917833        1.449477        291.82356
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```
## 2            25.47241        0.953059        1.241419        227.49063
## 3            22.15293        0.774121        2.674531        165.69391
## 4             2.79079        0.880393        1.732322       2033.70698
## 5            53.29819        0.741090        2.918639         99.23077
## 6            21.85351        0.720078        3.392842        140.39293
##   RP_align.H.PET LGRE_align.H.PET HGRE_align.H.PET LGSRE_align.H.PET
## 1       0.888556         0.004341         1569.763          0.004198
## 2       0.935326         0.004349         1536.186          0.004223
## 3       0.710370         0.003527         1821.062          0.003336
## 4       0.839415         0.005339         1588.246          0.005019
## 5       0.684948         0.002975         2476.679          0.002849
## 6       0.656286         0.003229         2111.778          0.003040
##   HGSRE_align.H.PET LGHRE_align.H.PET HGLRE_align.H.PET GLNU_norm_align.H.PET
## 1          1433.081          0.005120          2278.993              0.130158
## 2          1472.727          0.004991          1836.812              0.108781
## 3          1318.500          0.004849          5694.966              0.309012
## 4          1388.818          0.007300          2734.362              0.120339
## 5          1889.628          0.003929          6544.325              0.470904
## 6          1501.696          0.004877          7061.132              0.374988
##   RLNU_norm_align.H.PET GLVAR_align.H.PET RLVAR_align.H.PET Entropy_align.H.PET
## 1              0.805658         271.94120          0.166759             3.665844
## 2              0.881876         263.05257          0.089416             3.807145
## 3              0.559747         231.23849          0.633026             2.962910
## 4              0.733600         302.00409          0.279758             3.963763
## 5              0.516961          63.36076          0.708711             2.615080
## 6              0.492823         187.63061          0.894173             2.953297
##   SZSE.H.PET LZSE.H.PET LGLZE.H.PET HGLZE.H.PET SZLGE.H.PET SZHGE.H.PET
## 1   0.729896   6.346008    0.004206    1945.242    0.003751   1205.4141
## 2   0.889774   1.945761    0.004294    1541.326    0.004071   1371.5287
## 3   0.543152  38.343615    0.003595    1869.824    0.003145    833.9286
## 4   0.686000  28.192087    0.005281    2614.722    0.004412   1088.6316
## 5   0.494282  85.120177    0.002930    2778.032    0.002719   1427.6154
## 6   0.494144 151.989372    0.003258    2079.108    0.002893    988.7421
##   LZLGE.H.PET LZHGE.H.PET GLNU_area.H.PET ZSNU.H.PET ZSP.H.PET GLNU_norm.H.PET
## 1    0.014967    9278.763        28.21123  112.61992  0.564877        0.125177
## 2    0.007054    2730.177        23.91083  171.00253  0.829245        0.106933
## 3    0.027806   99597.669        42.33586   36.25834  0.312626        0.330695
## 4    0.066848   39940.885       160.59767  604.01684  0.425782        0.117405
## 5    0.047180  166256.576        23.73782   17.00253  0.245387        0.351578
## 6    0.115459  288928.476        28.02885   17.76569  0.181354        0.371297
##   ZSNU_norm.H.PET GLVAR_area.H.PET ZSVAR_H.PET Entropy_area.H.PET
## 1        0.492171        263.01858    3.183797           4.580974
## 2        0.749255        257.55868    0.482612           4.158935
## 3        0.283583        218.15517   27.944240           4.080320
## 4        0.434586        309.53854   22.609920           5.086907
## 5        0.252530         70.97225   68.165160           3.954518
## 6        0.236256        205.12926  120.717731           4.002762
##   Max_cooc.W.PET Average_cooc.W.PET Variance_cooc.W.PET Entropy_cooc.W.PET
## 1       0.013277           8.741717           27.724284           8.310617
## 2       0.015738          10.946398           54.254568           8.954940
## 3       0.046074           4.019422            3.648015           5.580950
## 4       0.013915           9.152454           25.597213           8.286935
## 5       0.116685           2.577872            2.729045           4.706665
## 6       0.063098           3.127779            2.391005           5.013592
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```
##   DAVE_cooc.W.PET DVAR_cooc.W.PET DENT_cooc.W.PET SAVE_cooc.W.PET
## 1        4.361115       12.870015        3.611785       17.480905
## 2        6.845926       31.128005        4.224171       21.890266
## 3        1.595373        1.629296        2.279633        8.036314
## 4        3.728549       11.060383        3.431589       18.302378
## 5        1.376959        1.728999        2.205393        5.153215
## 6        1.306368        1.277859        2.076037        6.253029
##   SVAR_cooc.W.PET SENT_cooc.W.PET ASM_cooc.W.PET Contrast_cooc.W.PET
## 1       79.024802        5.099087       0.006555           31.867274
## 2      139.053134        5.483416       0.005298           77.960077
## 3       10.420558        3.676978       0.027061            4.166444
## 4       77.440194        5.106053       0.007012           24.943599
## 5        7.293066        3.190894       0.061557            3.618055
## 6        6.581107        3.336839       0.041094            2.977854
##   Dissimilarity_cooc.W.PET Inv_diff_cooc.W.PET Inv_diff_norm_cooc.W.PET
## 1                 4.361115            0.306285                 0.861048
## 2                 6.845926            0.244001                 0.837985
## 3                 1.595373            0.503481                 0.863798
## 4                 3.728549            0.343449                 0.905179
## 5                 1.376959            0.558453                 0.882471
## 6                 1.306368            0.553594                 0.874095
##   IDM_cooc.W.PET IDM_norm_cooc.W.PET Inv_var_cooc.W.PET Correlation_cooc.W.PET
## 1       0.213874            0.955388           0.224294               0.427805
## 2       0.158456            0.936467           0.164222               0.284054
## 3       0.439777            0.957440           0.421156               0.431424
## 4       0.254836            0.980367           0.261941               0.515299
## 5       0.509374            0.964322           0.439330               0.339500
## 6       0.504966            0.961979           0.468899               0.379680
##   Autocorrelation_cooc.W.PET Tendency_cooc.W.PET Shade_cooc.W.PET
## 1                  88.165309           79.024802       341.143402
## 2                 135.044039          139.053134       552.913441
## 3                  17.701479           10.420558         2.361775
## 4                  96.847788           77.440194       471.374078
## 5                   7.553672            7.293066        26.823935
## 6                  10.670526            6.581107         7.170907
##   Prominence_cooc.W.PET IC1_d.W.PET IC2_d.W.PET Coarseness_vdif.W.PET
## 1            15813.1737   -0.042283    0.565302              0.015034
## 2            45767.4163   -0.044029    0.591913              0.015811
## 3              242.8423   -0.052987    0.524822              0.017811
## 4            21312.7505   -0.056187    0.630354              0.004934
## 5              276.1447   -0.033151    0.398878              0.018221
## 6              124.4042   -0.044775    0.466821              0.017235
##   Contrast_vdif.W.PET Busyness_vdif.W.PET Complexity_vdif.W.PET
## 1            0.294464            0.717283             869.48613
## 2            0.599158            0.420854            2313.88985
## 3            0.112568            2.860859              40.08855
## 4            0.133588            1.549091            1346.28621
## 5            0.078944            3.650188              44.97271
## 6            0.079545            4.181398              27.61148
##   Strength_vdif.W.PET SRE_align.W.PET LRE_align.W.PET GLNU_align.W.PET
## 1            3.919855        0.961787        1.191350         24.97624
## 2            8.341981        0.977438        1.116168         14.88136
## 3            0.511453        0.889821        1.618702         53.72505
## 4            1.384522        0.943354        1.291573        179.17215
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## 5            1.109636        0.876250        1.674603         59.72108
## 6            0.444774        0.863194        1.800706         67.44333
##   RLNU_align.W.PET RP_align.W.PET LGRE_align.W.PET HGRE_align.W.PET
## 1         347.5995       0.947236         0.150278        85.345885
## 2         250.6373       0.968373         0.127690       139.175484
## 3         265.0196       0.853307         0.272808        15.983362
## 4        2609.2747       0.922696         0.092857       101.288786
## 5         170.2453       0.840992         0.466475         7.937118
## 6         245.9412       0.822440         0.339659        10.636341
##   LGSRE_align.W.PET HGSRE_align.W.PET LGHRE_align.W.PET HGLRE_align.W.PET
## 1          0.144360         82.365395          0.178628          98.96776
## 2          0.122525        136.722689          0.150485         150.71592
## 3          0.245883         13.790048          0.414898          28.12741
## 4          0.087782         95.978334          0.117784         126.22675
## 5          0.401364          7.231352          0.833918          11.22377
## 6          0.297964          9.120687          0.601806          18.69612
##   GLNU_norm_align.W.PET RLNU_norm_align.W.PET GLVAR_align.W.PET
## 1              0.067162              0.901536         27.361255
## 2              0.058138              0.938874         51.482886
## 3              0.154351              0.749487          3.691659
## 4              0.061479              0.859819         27.190856
## 5              0.256845              0.724823          2.405984
## 6              0.196000              0.702794          2.523334
##   RLVAR_align.W.PET Entropy_align.W.PET SZSE.W.PET LZSE.W.PET LGLZE.W.PET
## 1          0.069370            4.413771   0.862196   2.111226    0.136626
## 2          0.043126            4.601911   0.939019   1.436265    0.126898
## 3          0.229632            3.470022   0.737823   5.821460    0.309701
## 4          0.107059            4.683410   0.816094   3.396694    0.091699
## 5          0.239812            2.974484   0.688181   6.186741    0.438075
## 6          0.289495            3.306066   0.662526  12.143891    0.342286
##   HGLZE.W.PET SZLGE.W.PET SZHGE.W.PET LZLGE.W.PET LZHGE.W.PET GLNU_area.W.PET
## 1   88.918679    0.112325   79.094274    0.392257   161.03980        20.13918
## 2  138.464377    0.116457  128.987889    0.195656   189.79771        13.47643
## 3   14.973723    0.247502   10.310508    1.043890   117.40582        38.33586
## 4  106.496868    0.073436   88.831921    0.286957   297.89713       131.17762
## 5    9.015688    0.284427    6.692377    3.360406    31.91043        35.02885
## 6   10.745985    0.252353    6.482655    5.046844   107.42661        36.93970
##   ZSNU.W.PET ZSP.W.PET GLNU_norm.W.PET ZSNU_norm.W.PET GLVAR_area.W.PET
## 1  224.38141  0.789816        0.065066        0.699359        27.622423
## 2  211.55675  0.901447        0.056642        0.852145        50.978030
## 3  121.85027  0.586665        0.160280        0.503961         3.807675
## 4 1419.26821  0.697656        0.059662        0.620677        29.116647
## 5   66.31832  0.545387        0.232966        0.438818         2.699725
## 6   77.07583  0.451942        0.195918        0.406055         2.633927
##   ZSVAR.W.PET Entropy_area.W.PET Min_hist.ADC Max_hist.ADC Mean_hist.ADC
## 1    0.497852           4.937916    549.00253     2268.003      1238.232
## 2    0.198720           4.834988      0.00253     2211.003      1158.946
## 3    2.890741           4.143192    634.00253     2860.003      1252.476
## 4    1.327156           5.449999      0.00253     2869.003      1195.303
## 5    2.793389           3.991207      0.00253     2389.003      1022.390
## 6    7.192684           4.330361      0.00253     2498.003      1344.979
##   Variance_hist.ADC Standard_Deviation_hist.ADC Skewness_hist.ADC
## 1         113473.17                    336.8603           1.05752
## 2          83953.26                    289.7494          -0.49105
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## 3         193194.07                   439.5410           1.53649
## 4         132561.08                   364.0919           0.24067
## 5         110268.35                   332.0693           0.31916
## 6         276984.10                   526.2953          -0.19996
##   Kurtosis_hist.ADC Energy_hist.ADC Entropy_hist.ADC AUC_hist.ADC Volume.ADC
## 1           0.39978         0.00757          7.72697      0.52307   14702.81
## 2           1.41215         0.00503          8.82392      0.49147   11850.17
## 3           2.15473         0.00426          9.42564      0.56722   26067.89
## 4           0.23359         0.00365         10.02927      0.52148   51577.90
## 5           0.50069         0.00454          9.12787      0.50458   27419.14
## 6          -1.03080         0.00413          9.41989      0.49047   16131.31
##   X3D_surface.ADC ratio_3ds_vol.ADC ratio_3ds_vol_norm.ADC irregularity.ADC
## 1        2621.908           0.39370                1.52762          1.93975
## 2        3814.097           0.27791                1.37006          1.76130
## 3        5638.645           0.21884                1.32876          1.57930
## 4       11033.100           0.21644                1.64907          1.63673
## 5        5670.769           0.22562                1.35892          1.61457
## 6        6099.528           0.30552                1.70690          1.72859
##   Compactness_v1.ADC Compactness_v2.ADC Spherical_disproportion.ADC
## 1            0.03070            0.28444                     1.52762
## 2            0.03570            0.39354                     1.37006
## 3            0.03727            0.43122                     1.32876
## 4            0.02764            0.22655                     1.64907
## 5            0.03611            0.40326                     1.35892
## 6            0.02637            0.20451                     1.70690
##   Sphericity.ADC Asphericity.ADC Center_of_mass.ADC Max_3D_diam.ADC
## 1        0.65823         0.52762            0.97407        46.80855
## 2        0.73378         0.37006            1.00173        57.64178
## 3        0.75655         0.32876            1.48789        64.07496
## 4        0.60987         0.64907            1.32794        85.02235
## 5        0.73978         0.35892            0.57983        59.88998
## 6        0.58926         0.70690            1.60559        66.42410
##   Major_axis_length.ADC Minor_axis_length.ADC Least_axis_length.ADC
## 1              45.53640              20.24517              13.58989
## 2              35.07877              28.70241              23.63536
## 3              42.14714              36.72698              25.93458
## 4              58.00549              42.98623              35.06326
## 5              39.28351              35.40209              31.13508
## 6              52.01087              34.53146              21.82211
##   Elongation.ADC Flatness.ADC Max_cooc.L.ADC Average_cooc.L.ADC
## 1        0.44709      0.30093        0.01362           24.26969
## 2        0.82074      0.67629        0.00769           34.15443
## 3        0.87392      0.61784        0.00984           17.40595
## 4        0.74359      0.60699        0.00893           26.20041
## 5        0.90372      0.79509        0.00863           27.03123
## 6        0.66644      0.42207        0.00548           33.31549
##   Variance_cooc.L.ADC Entropy_cooc.L.ADC DAVE_cooc.L.ADC DVAR_cooc.L.ADC
## 1           135.95808            9.35172         9.33833        95.10941
## 2            60.59539            9.52569         6.58341        31.97649
## 3           159.14565            9.93157         8.05607        81.58702
## 4            57.02199            9.50974         5.46198        23.67951
## 5            65.76514            9.76494         6.96837        33.58727
## 6           176.68232           10.64861         9.13371        70.36682
##   DENT_cooc.L.ADC SAVE_cooc.L.ADC SVAR_cooc.L.ADC SENT_cooc.L.ADC
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## 1         4.68745        48.53685        361.5607         4.49616
## 2         4.18551        68.30632        167.0920         2.32433
## 3         4.48343        34.80936        490.1310         5.16708
## 4         3.95039        52.39829        174.5978         4.55938
## 5         4.26293        54.05993        180.9453         4.48500
## 6         4.65758        66.62846        552.9789         3.08233
##   ASM_cooc.L.ADC Contrast_cooc.L.ADC Dissimilarity_cooc.L.ADC
## 1        0.00535           182.26652                  9.33833
## 2        0.00448            75.28447                  6.58341
## 3        0.00458           146.44656                  8.05607
## 4        0.00454            53.48506                  5.46198
## 5        0.00414            82.11021                  6.96837
## 6        0.00338           153.74529                  9.13371
##   Inv_diff_cooc.L.ADC Inv_diff_norm_cooc.L.ADC IDM_cooc.L.ADC
## 1             0.23569                 0.88844        0.15619
## 2             0.24103                 0.91456        0.15044
## 3             0.24921                 0.90225        0.16496
## 4             0.27847                 0.92805        0.18834
## 5             0.23450                 0.90993        0.14567
## 6             0.20980                 0.88787        0.12604
##   IDM_norm_cooc.L.ADC Inv_var_cooc.L.ADC Correlation_cooc.L.ADC
## 1             0.96528            0.15633                0.33222
## 2             0.98542            0.15887                0.38132
## 3             0.97276            0.17144                0.54243
## 4             0.99019            0.19368                0.53355
## 5             0.98376            0.15283                0.37826
## 6             0.96963            0.13018                0.56744
##   Autocorrelation_.L.ADC Tendency_cooc.L.ADC Shade_.L.ADC Prominence_cooc.L.ADC
## 1               633.7211            361.5607    7639.8939             517154.08
## 2              1189.3065            167.0920   -1156.8109             112937.29
## 3               388.8025            490.1310   17093.4493            1296059.93
## 4               716.6097            174.5978     616.3283              88605.95
## 5               755.2618            180.9453     592.0947             113320.37
## 6              1209.5645            552.9789   -1837.1897             590287.94
##   IC1_.L.ADC IC2_.L.ADC Coarseness_vdif_.L.ADC Contrast_vdif_.L.ADC
## 1   -0.11842    0.83912                0.02135               0.71307
## 2   -0.05061    0.63924                0.01258               0.23808
## 3   -0.07274    0.73740                0.00784               0.40394
## 4   -0.06200    0.68774                0.00556               0.15512
## 5   -0.04812    0.63329                0.01085               0.27967
## 6   -0.09225    0.81078                0.01042               0.60161
##   Busyness_vdif_.L.ADC Complexity_vdif_.L.ADC Strength_vdif_.L.ADC
## 1              0.04811               8748.919             30.44366
## 2              0.05243               5213.433             10.85376
## 3              0.21602               9811.189             12.83805
## 4              0.20181               4912.319              3.52728
## 5              0.08515               5705.778              8.31391
## 6              0.06946               8974.106             10.09240
##   SRE_align.L.ADC LRE_align.L.ADC GLNU_align.L.ADC RLNU_align.L.ADC
## 1         0.97677         1.11587          9.40856         232.7602
## 2         0.97564         1.11803         26.43616         645.9593
## 3         0.96919         1.14834         43.70925        1177.5699
## 4         0.96126         1.18592        102.31243        2562.1046
## 5         0.97703         1.11715         28.40221         788.2562
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## 6         0.98211         1.08986         21.25471         890.8892
##   RP_align.L.ADC LGRE_align.L.ADC HGRE_align.L.ADC LGSRE_align.L.ADC
## 1        0.96871          0.00908         831.5410           0.00900
## 2        0.96669          0.00605        1191.1595           0.00602
## 3        0.95823          0.01361         487.9258           0.01321
## 4        0.94795          0.00810         786.0107           0.00784
## 5        0.96795          0.00721         833.8975           0.00716
## 6        0.97551          0.00591        1362.5846           0.00587
##   HGSRE_align.L.ADC LGHRE_align.L.ADC HGLRE_align.L.ADC GLNU_norm_align.L.ADC
## 1          820.9252           0.00946          876.2823               0.04038
## 2         1157.5280           0.00615         1335.5219               0.04066
## 3          478.4817           0.01531          528.1310               0.03656
## 4          757.7992           0.00954          909.4492               0.03841
## 5          815.1979           0.00741          917.7657               0.03626
## 6         1335.9421           0.00607         1478.8704               0.02516
##   RLNU_norm_align.L.ADC GLVAR_align.L.ADC RLVAR_align.L.ADC Entropy_align.L.ADC
## 1               0.93826         154.93296           0.04141              5.29371
## 2               0.93411          69.45486           0.04188              5.17751
## 3               0.91877         156.30297           0.05240              5.47452
## 4               0.90022          64.98946           0.06534              5.31012
## 5               0.93819          78.05347           0.04295              5.30441
## 6               0.95061         175.82591           0.03219              5.74239
##   SZSE.L.ADC LZSE.L.ADC LGLZE.L.ADC HGLZE.L.ADC SZLGE.L.ADC SZHGE.L.ADC
## 1    0.93703    1.33159     0.00927    858.5837     0.00905    831.8537
## 2    0.92448    1.39444     0.00624   1184.8610     0.00617   1086.4222
## 3    0.87706    1.82170     0.01338    514.4899     0.01189    468.7768
## 4    0.90217    1.59820     0.00767    792.5723     0.00686    720.2240
## 5    0.91279    1.55603     0.00757    833.3315     0.00743    760.6074
## 6    0.93634    1.29245     0.00606   1348.0807     0.00598   1247.0381
##   LZLGE.L.ADC LZHGE.L.ADC GLNU_area.L.ADC ZSNU.L.ADC ZSP.L.ADC GLNU_norm.L.ADC
## 1     0.01042    981.8102         8.25894   197.1051   0.91304         0.03781
## 2     0.00662   1681.2171        24.10984   524.4053   0.89683         0.04002
## 3     0.02376    734.9103        34.98083   798.7819   0.82545         0.03416
## 4     0.01300   1204.1618        90.93063  1994.0215   0.86029         0.03768
## 5     0.00840   1283.7978        24.73040   600.5032   0.87065         0.03520
## 6     0.00644   1779.7534        19.65712   741.6164   0.91756         0.02479
##   ZSNU_norm.L.ADC GLVAR_area.L.ADC ZSVAR.L.ADC Entropy_area.L.ADC
## 1         0.84485        158.37071     0.12535            5.53926
## 2         0.81809         71.19097     0.14408            5.46224
## 3         0.72475        157.77185     0.34501            6.00431
## 4         0.77331         66.76247     0.23904            5.67242
## 5         0.79579         82.41219     0.22912            5.69671
## 6         0.84241        176.08461     0.09810            6.01150
##   Max_cooc.H.ADC Average_cooc.H.ADC Variance_cooc.H.ADC Entropy_cooc.H.ADC
## 1        0.00464           29.95976            310.9790           11.72265
## 2        0.00420           33.61846            312.8265           11.35537
## 3        0.00622           30.58315            335.7248           11.53210
## 4        0.00461           30.75681            310.6464           11.60919
## 5        0.00393           31.26939            305.7453           11.56749
## 6        0.00496           30.52540            330.9954           11.34674
##   DAVE_cooc.H.ADC DVAR_cooc.H.ADC DENT_cooc.H.ADC SAVE_cooc.H.ADC
## 1        15.71847        162.7022         5.37436        59.91700
## 2        15.39980        148.1637         5.34697        67.23440
## 3        13.82367        148.1751         5.24052        61.16377
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## 4        12.67796        118.4962         5.12061        61.51110
## 5        15.22805        152.9835         5.34969        62.53624
## 6        12.68957        134.2114         5.12373        61.04826
##   SVAR_cooc.H.ADC SENT_cooc.H.ADC ASM_cooc.H.ADC Contrast_cooc.H.ADC
## 1        834.2180         3.87272        0.00312            409.6931
## 2        866.0614         3.21841        0.00292            385.2396
## 3       1003.6953         3.81762        0.00296            339.1990
## 4        963.4178         3.73436        0.00290            279.1628
## 5        838.1762         3.61892        0.00291            384.8001
## 6       1028.8043         3.58842        0.00300            295.1723
##   Dissimilarity_cooc.H.ADC Inv_diff_cooc.H.ADC Inv_diff_norm_cooc.H.ADC
## 1                 15.71847             0.14449                  0.82408
## 2                 15.39980             0.13871                  0.82594
## 3                 13.82367             0.16711                  0.84276
## 4                 12.67796             0.16941                  0.85215
## 5                 15.22805             0.14798                  0.82834
## 6                 12.68957             0.17461                  0.85365
##   IDM_cooc.H.ADC IDM_norm_cooc.H.ADC Inv_var_cooc.H.ADC Correlation_cooc.H.ADC
## 1        0.07807             0.92422            0.08536                0.34381
## 2        0.06993             0.92757            0.07472                0.38679
## 3        0.09608             0.93697            0.09823                0.49736
## 4        0.09588             0.94673            0.09742                0.55321
## 5        0.07991             0.92793            0.08208                0.37325
## 6        0.09995             0.94500            0.10213                0.55665
##   Autocorrelation_cooc.H.ADC Tendency_cooc.H.ADC Shade_cooc.H.ADC
## 1                   1003.570            834.2180       4888.58538
## 2                   1250.239            866.0614      -4080.74039
## 3                   1101.301           1003.6953       7361.25628
## 4                   1116.892            963.4178       2723.56893
## 5                   1090.963            838.1762        -98.86912
## 6                   1115.056           1028.8043        509.16337
##   Prominence_cooc.H.ADC IC1_d.H.ADC IC2_d.H.ADC Coarseness_vdif.H.ADC
## 1               1518300    -0.15943     0.92667               0.02421
## 2               1589114    -0.05988     0.72703               0.01048
## 3               2077405    -0.06514     0.74687               0.00767
## 4               1824192    -0.05338     0.70043               0.00496
## 5               1538643    -0.05818     0.72034               0.00898
## 6               1971550    -0.09605     0.83415               0.00994
##   Contrast_vdif.H.ADC Busyness_vdif.H.ADC Complexity_vdif.H.ADC
## 1             1.85757             0.03586              16806.66
## 2             1.80534             0.09301              16186.56
## 3             1.49359             0.14284              13464.93
## 4             1.41213             0.29907              12641.54
## 5             1.83534             0.11398              16384.39
## 6             1.45238             0.09984              12914.39
##   Strength_vdif.H.ADC SRE_align.H.ADC LRE_align.H.ADC GLNU_align.H.ADC
## 1            29.66079         0.99220         1.04664          4.07230
## 2            10.90410         0.99123         1.04949         11.31108
## 3             7.03589         0.98442         1.08787         20.88959
## 4             3.31909         0.98263         1.08821         46.68109
## 5             8.83863         0.98826         1.06328         13.66324
## 6            10.10115         0.98601         1.07180         15.03108
##   RLNU_align.H.ADC RP_align.H.ADC LGRE_align.H.ADC HGRE_align.H.ADC
## 1         246.9236        0.98876          0.02752         1363.457
```

```
## 2         687.6470        0.98755          0.02717         1357.005
## 3        1249.7235        0.97718          0.02776         1343.165
## 4        2786.7832        0.97588          0.02638         1359.587
## 5         824.1350        0.98339          0.02668         1358.525
## 6         904.6320        0.98077          0.02665         1361.936
##   LGSRE_align.H.ADC HGSRE_align.H.ADC LGHRE_align.H.ADC HGLRE_align.H.ADC
## 1           0.02695          1349.190           0.02979          1430.871
## 2           0.02648          1340.025           0.02994          1430.336
## 3           0.02707          1310.372           0.03080          1516.790
## 4           0.02500          1334.267           0.03403          1466.691
## 5           0.02577          1338.937           0.03083          1444.863
## 6           0.02539          1342.295           0.03304          1444.991
##   GLNU_norm_align.H.ADC RLNU_norm_align.H.ADC GLVAR_align.H.ADC
## 1               0.01859               0.97614          329.5023
## 2               0.01850               0.97320          329.3505
## 3               0.01848               0.95625          325.6524
## 4               0.01843               0.95150          327.9251
## 5               0.01850               0.96576          329.3047
## 6               0.01845               0.96023          327.5799
##   RLVAR_align.H.ADC Entropy_align.H.ADC SZSE.H.ADC LZSE.H.ADC LGLZE.H.ADC
## 1           0.01753             6.01510    0.96829    1.15763     0.02871
## 2           0.01839             6.04615    0.96505    1.15896     0.02661
## 3           0.03446             6.10308    0.93628    1.65499     0.02502
## 4           0.03209             6.13418    0.95168    1.26414     0.02388
## 5           0.02330             6.06848    0.95866    1.24670     0.02517
## 6           0.02577             6.08534    0.94459    1.30242     0.02141
##   HGLZE.H.ADC SZLGE.H.ADC SZHGE.H.ADC LZLGE.H.ADC LZHGE.H.ADC GLNU_area.H.ADC
## 1    1353.052     0.02838    1303.023     0.03004    1618.472         3.99028
## 2    1355.552     0.02483    1302.738     0.03376    1584.380        10.95282
## 3    1293.549     0.02152    1196.086     0.04888    2953.476        19.42358
## 4    1353.634     0.02049    1283.290     0.04521    1725.853        44.63370
## 5    1328.345     0.02373    1252.666     0.04477    1783.557        13.08842
## 6    1363.271     0.01864    1280.446     0.06832    1716.544        14.22012
##   ZSNU.H.ADC ZSP.H.ADC GLNU_norm.H.ADC ZSNU_norm.H.ADC GLVAR_area.H.ADC
## 1   223.9086   0.95584         0.01881         0.91643         324.0822
## 2   619.2862   0.95385         0.01854         0.90792         327.6186
## 3  1007.9399   0.89316         0.01876         0.84458         305.6363
## 4  2450.9039   0.93025         0.01848         0.87848         321.4979
## 5   727.4123   0.93716         0.01859         0.89506         324.1160
## 6   762.1457   0.92170         0.01856         0.86177         315.8327
##   ZSVAR.H.ADC Entropy_area.H.ADC Max_cooc.W.ADC Average_cooc.W.ADC
## 1     0.05727            6.06723        0.00675           65.37977
## 2     0.05401            6.18594        0.00382          118.60405
## 3     0.39430            6.37088        0.00376           60.27417
## 4     0.10225            6.32299        0.00302          117.52784
## 5     0.10193            6.21756        0.00355          101.18139
## 6     0.11881            6.31556        0.00343          130.61014
##   Variance_cooc.W.ADC DAVE_cooc.W.ADC DVAR_cooc.W.ADC DENT_cooc.W.ADC
## 1           1010.0875        25.43812        706.5272         6.06338
## 2            746.1691        23.15154        390.8192         5.94785
## 3           1991.6618        28.49457       1018.7085         6.25261
## 4           1181.5174        24.91785        487.4797         6.07963
## 5            945.7911        26.38488        481.6157         6.14012
## 6           2779.9243        36.21365       1103.2759         6.60187
```

```
##   SAVE_cooc.W.ADC SVAR_cooc.W.ADC SENT_cooc.W.ADC ASM_cooc.W.ADC
## 1        130.7570        2686.849         5.54316        0.00323
## 2        237.2056        2057.975         2.77584        0.00280
## 3        120.5458        6136.137         6.76239        0.00275
## 4        235.0531        3617.812         6.13864        0.00265
## 5        202.3602        2605.515         5.80987        0.00273
## 6        261.2178        8705.171         3.87339        0.00266
##   Contrast_cooc.W.ADC Dissimilarity_cooc.W.ADC Inv_diff_cooc.W.ADC
## 1            1353.496                25.43812             0.12826
## 2             926.696                23.15154             0.10420
## 3            1830.505                28.49457             0.10990
## 4            1108.253                24.91785             0.10456
## 5            1177.644                26.38488             0.09861
## 6            2414.521                36.21365             0.08344
##   Inv_diff_norm_cooc.W.ADC IDM_cooc.W.ADC IDM_norm_cooc.W.ADC
## 1                  0.88720        0.06987             0.96438
## 2                  0.91342        0.04700             0.98505
## 3                  0.90097        0.05282             0.97202
## 4                  0.92684        0.04905             0.98983
## 5                  0.90880        0.04557             0.98327
## 6                  0.88642        0.03696             0.96879
##   Inv_var_cooc.W.ADC Correlation_cooc.W.ADC Autocorrelation_cooc.W.ADC
## 1            0.07218                0.33254                   4607.525
## 2            0.04790                0.38156                  14349.142
## 3            0.05640                0.54299                   4709.081
## 4            0.04962                0.53354                  14439.590
## 5            0.04452                0.37996                  10594.131
## 6            0.03757                0.56825                  18631.013
##   Tendency_cooc.W.ADC Shade_cooc.W.ADC Prominence_cooc.W.ADC IC1_d.W.ADC
## 1            2686.849        154504.57              28492973    -0.20561
## 2            2057.975        -49857.50              17100002    -0.13210
## 3            6136.137        755229.72             202604689    -0.13981
## 4            3617.812         57995.75              38091821    -0.08828
## 5            2605.515         31890.26              23457384    -0.13836
## 6            8705.171       -113889.96             146542333    -0.23037
##   IC2_d.W.ADC Coarseness_vdif.W.ADC Contrast_vdif.W.ADC Busyness_vdif.W.ADC
## 1     0.96152               0.01818             4.78265              0.01774
## 2     0.91270               0.01162             1.49489              0.00979
## 3     0.92904               0.00742             1.99390              0.02744
## 4     0.85241               0.00544             1.11708              0.01846
## 5     0.92596               0.01002             1.72379              0.01257
## 6     0.98684               0.00959             3.20701              0.00873
##   Complexity_vdif.W.ADC Strength_vdif.W.ADC SRE_align.W.ADC LRE_align.W.ADC
## 1              94483.95           120.21874         0.99193         1.04495
## 2             123984.35            70.45906         0.99469         1.03484
## 3             322896.60           118.12334         0.99389         1.03917
## 4             270786.27            41.10745         0.99307         1.04143
## 5             183481.75            68.98942         0.99446         1.03681
## 6             408132.18           116.30778         0.99699         1.02540
##   GLNU_align.W.ADC RLNU_align.W.ADC RP_align.W.ADC LGRE_align.W.ADC
## 1          4.26622         246.5777        0.98876          0.00683
## 2          8.60033         696.8829        0.99205          0.00418
## 3         13.91071        1298.3291        0.99080          0.00430
## 4         24.38419        2904.1988        0.98991          0.00579
```

```
## 5          8.43212         844.4260        0.99159          0.00400
## 6          6.05624         944.0342        0.99512          0.00374
##   HGRE_align.W.ADC LGSRE_align.W.ADC HGSRE_align.W.ADC LGHRE_align.W.ADC
## 1         5992.756           0.00683          5952.927           0.00685
## 2        14395.425           0.00418         14281.115           0.00418
## 3         5853.808           0.00429          5824.143           0.00434
## 4        15776.936           0.00562         15649.652           0.00681
## 5        11683.555           0.00400         11599.962           0.00400
## 6        21008.240           0.00373         20894.393           0.00374
##   HGLRE_align.W.ADC GLNU_norm_align.W.ADC RLNU_norm_align.W.ADC
## 1          6152.074               0.01935               0.97502
## 2         14868.922               0.01462               0.98198
## 3          5983.117               0.01300               0.97996
## 4         16293.667               0.01072               0.97773
## 5         12044.998               0.01230               0.98150
## 6         21478.153               0.00885               0.98802
##   GLVAR_align.W.ADC RLVAR_align.W.ADC Entropy_align.W.ADC SZSE.W.ADC LZSE.W.ADC
## 1         1139.4041           0.01629             6.94511    0.98460    1.07424
## 2          842.8456           0.01345             6.67452    0.96527    1.11797
## 3         1938.7178           0.01519             6.79621    0.98765    1.17872
## 4         1327.6869           0.01562             7.20649    0.98060    1.10239
## 5         1109.3728           0.01437             6.95074    0.97667    1.13245
## 6         2767.6284           0.01027             7.49193    0.98323    1.08445
##   LGLZE.W.ADC HGLZE.W.ADC SZLGE.W.ADC SZHGE.W.ADC LZLGE.W.ADC LZHGE.W.ADC
## 1     0.00686    6055.150     0.00686    6018.454     0.00690    6201.935
## 2     0.00422   14407.506     0.00422   14026.413     0.00423   16054.013
## 3     0.00433    5883.686     0.00430    5711.245     0.00453    6674.638
## 4     0.00511   15809.845     0.00455   15506.485     0.00888   17172.910
## 5     0.00403   11663.603     0.00403   11366.888     0.00405   13231.943
## 6     0.00376   20996.110     0.00375   20573.429     0.00377   22707.428
##   GLNU_area.W.ADC ZSNU.W.ADC ZSP.W.ADC GLNU_norm.W.ADC ZSNU_norm.W.ADC
## 1         4.13400   239.2894   0.97918         0.01899         0.95586
## 2         8.37627   644.7370   0.95637         0.01461         0.93288
## 3        13.11686  1165.7026   0.97268         0.02501         0.91537
## 4        23.84726  2760.4129   0.97203         0.01069         0.94658
## 5         8.14437   784.5973   0.96469         0.02526         0.93769
## 6         5.93657   893.1791   0.97662         0.00884         0.95272
##   GLVAR_area.W.ADC ZSVAR.W.ADC Entropy_area.W.ADC
## 1        1145.1050     0.02586            6.28632
## 2         847.5254     0.04153            6.77853
## 3        1923.8571     0.07104            7.15685
## 4        1329.9529     0.03848            7.29521
## 5        1116.3867     0.05223            7.05149
## 6        2743.2376     0.03055            7.54787
```

Data description

```
str(radiomics[1:10])
```

```
## 'data.frame':    197 obs. of  10 variables:
##  $ Institution               : chr  "A" "A" "A" "A" ...
##  $ Failure.binary            : int  0 1 0 1 0 1 0 0 1 1 ...
##  $ Failure                   : num  49.3 12.6 79.8 17.9 39.6 ...
##  $ Entropy_cooc.W.ADC        : num  12.9 12.2 12.8 13.5 12.6 ...
##  $ GLNU_align.H.PET          : num  46.3 27.5 90.2 325.6 89.6 ...
```

```
##  $ Min_hist.PET               : num  6.25 11.01 2.78 6.3 3.58 ...
##  $ Max_hist.PET               : num  17.83 26.47 6.88 22.03 7.92 ...
##  $ Mean_hist.PET              : num  9.78 15.43 4.3 10.33 4.45 ...
##  $ Variance_hist.PET          : num  6.814 12.932 0.923 6.65 0.572 ...
##  $ Standard_Deviation_hist.PET: num  2.612 3.598 0.962 2.581 0.757 ...
```

Variables *Institution* and *Failure.binary* needs to change its datatype into factors. `Institution` was re-coded into dummy variables

```
newdf = dummy_cols(radiomics, select_columns = "Institution" )
newdf = newdf[,-1]
str(newdf[431:434])
```

```
## 'data.frame':    197 obs. of  4 variables:
##  $ Institution_A: int  1 1 1 1 1 1 1 1 1 1 ...
##  $ Institution_B: int  0 0 0 0 0 0 0 0 0 0 ...
##  $ Institution_C: int  0 0 0 0 0 0 0 0 0 0 ...
##  $ Institution_D: int  0 0 0 0 0 0 0 0 0 0 ...
```

```
newdf$Institution_A = as.factor(newdf$Institution_A)
newdf$Institution_B = as.factor(newdf$Institution_B)
newdf$Institution_C = as.factor(newdf$Institution_C)
newdf$Institution_D = as.factor(newdf$Institution_D)
newdf$Failure.binary = as.factor(newdf$Failure.binary)
str(newdf[1])
```

```
## 'data.frame':    197 obs. of  1 variable:
##  $ Failure.binary: Factor w/ 2 levels "0","1": 1 2 1 2 1 2 1 1 2 2 ...
```

Null Values

```
sum(is.na(newdf))
```

```
## [1] 0
```

No null values found in the data.

Normality of the data

To check the normality of the data, we used Shapiro-wilk test.

SHAPIRO-WILK TEST OF NORMALITY H_o = Data is normally distributed H_i = Data is not normally distributed

```
lshap <- lapply(newdf[2:430], shapiro.test) #applying shapiro-wilk test of normality to the data frame
l = 1:429
for (i in l) { #
  x = lshap[[i]]$p.value
  z= 1 +i
  if (lshap[[i]]$p.value >= 0.05){
    print(paste(x, "p-value for",colnames(newdf[z]) ))
 }
}
```

```
## [1] "0.135011298030283 p-value for Entropy_cooc.W.ADC"
```

Upon checking its normality, only the *Entropy_cooc.W.ADC* has p-value of 0.135 which tells that it follows normal distribution,the rest of the variables do not follow normal distribution. Transformation is required to the data to address the non-normality of the data. In this project we use *Ordered Quantile (ORQ) normalization transformation* to normalize the data.

```
newdf1 = newdf %>% select_if(is.numeric)
tempDF=apply(newdf1,2,orderNorm)
tempDF=lapply(tempDF, function(x) x$x.t)
tempDF=tempDF%>%as.data.frame()
norm_data = cbind(newdf[c('Failure.binary','Institution_A','Institution_B','Institution_C','Institution
```

Testing the normality of the data using the normalize data using **Ordered Quantile (ORQ) normalization transformation**.

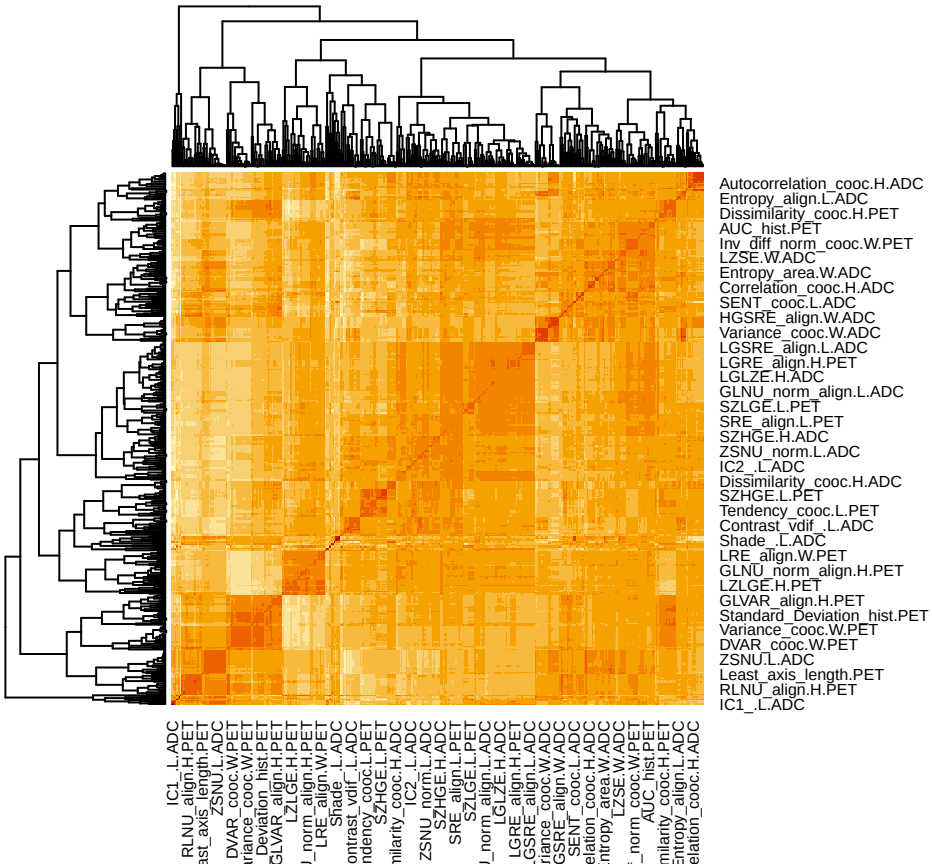
```
lshap <- lapply(tempDF, shapiro.test) #applying shapiro-wilk test of normality to the data frame
l = 1:429
for (i in l) { #
  x = lshap[[i]]$p.value
  z= 1 +i
  if (lshap[[i]]$p.value <= 0.05){
    print(paste(x, "p-value for",colnames(newdf[z]) ))
 }
}
```

Since all p-values are greater than 0.05 then we cannot reject the null hypothesis that the data by this time follows Normal distribution.

Correlation

Checking the correlation of the data. By assumption that highly correlated data does not do good in model making, thus by removing this will improve the performance of our model. But in this project, removing highy correlated columns is not considered.

```
heatmap(corMatrix)
```




```
#ggcorrplot(corr <= 0.40 ,colors =  c("blue", "white","red"), ggtheme=theme_bw, lab = FALSE, title = "C
```

Data Splitting

After pre-processing, we now split our data into 80% for training and 20% for testing. * **Training:** our training dataset has a 158 observations * **Testing:** our testing dataset has a 39 observations

```
set.seed(3333)
trainIndex <- createDataPartition(norm_data$Failure.binary, p = .80,
                                  list = FALSE,
                                  times = 1)
finaldata_train<- norm_data[ trainIndex,]
finaldata_test<- norm_data[-trainIndex,]
dim(finaldata_train) ; dim(finaldata_test)
```

```
## [1] 158 434
```

```
## [1]  39 434
```

DATA MODELING

Libraries Needed for Modeling

```
library(rpart)        # for fitting decision trees
library(ipred)        # for fitting bagged decision trees
library(doParallel)   # for parallel backend to foreach
library(foreach)      # for parallel processing with for loops
```

Bagging Model

1. This model uses bagging() function form `ipred` package. In this model we used 100 iterations to create 100 bootstrapped samples.

```
bagging_1 <- bagging(
  formula = Failure.binary ~ .,
  data = finaldata_train,
  nbagg = 100,  # number of iteration to be included in the model.
  coob = TRUE, # OOB error rate
  control = rpart.control(minsplit = 2, cp = 0)
)

bagging_1
```

```
##
## Bagging classification trees with 100 bootstrap replications
##
## Call: bagging.data.frame(formula = Failure.binary ~ ., data = finaldata_train,
##     nbagg = 100, coob = TRUE, control = rpart.control(minsplit = 2,
##         cp = 0))
##
## Out-of-bag estimate of misclassification error:  0.1203
```

From the output above, we obtain the Out-of-bag estimate of misclassification error of 0.1203. This means that model bagging_1 has a tendency of 12% misclassifying error in classifying the `Failure.binary` variable.

2. This model applied bagging from caret package with 10-fold cross-validation. The model has an accuracy of 0.875 which is good enough.

```
bagging_2 <- train(
  Failure.binary ~ .,
  data = finaldata_train,
  method = "treebag",
  trControl = trainControl(method = "cv", number = 10),
  nbagg = 200,
  control = rpart.control(minsplit = 2, cp = 0)
)

bagging_2
```

```
## Bagged CART
##
## 158 samples
## 433 predictors
##   2 classes: '0', '1'
##
## No pre-processing
## Resampling: Cross-Validated (10 fold)
## Summary of sample sizes: 141, 141, 143, 142, 142, 143, ...
## Resampling results:
##
##   Accuracy   Kappa
##   0.8800735  0.7309916
```

The model has accuracy of 88% in classifying the `Failure.binary` variable. To choose the best model we try to test the models performance on test set.

```
library(performance)
library(ROCR)
```

```
##
## Attaching package: 'ROCR'
```

```
## The following object is masked from 'package:performance':
##
##     performance
```

```
library(pROC)
```

```
## Type 'citation("pROC")' for a citation.
```

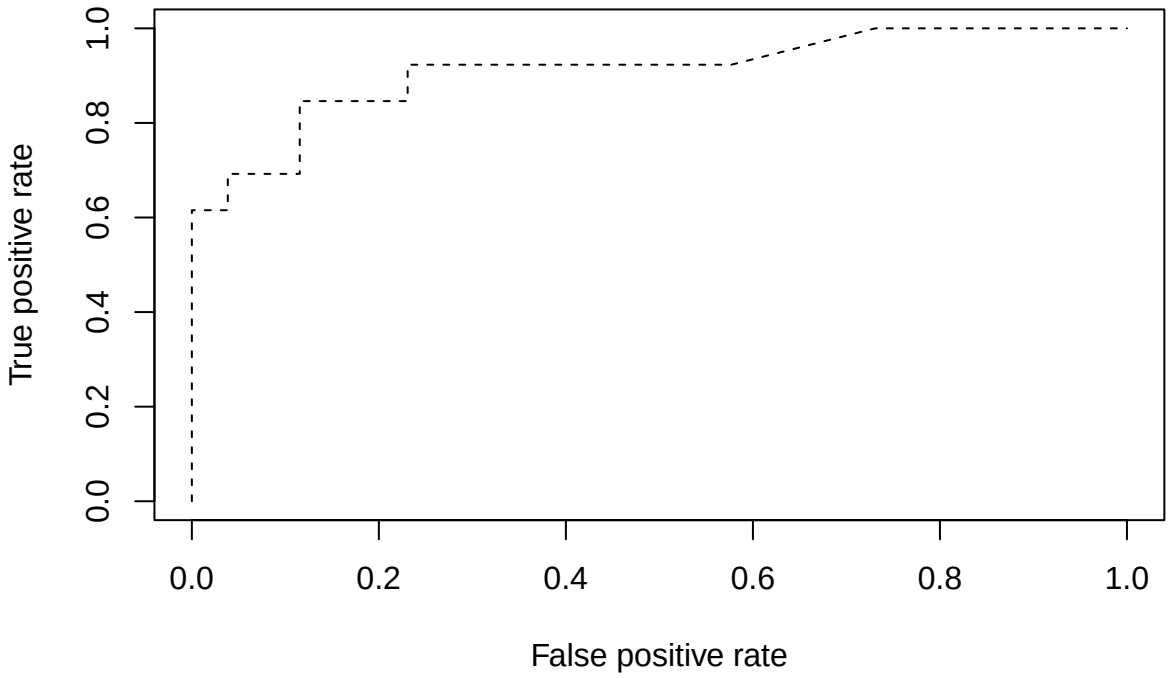
```
##
## Attaching package: 'pROC'
```

```
## The following objects are masked from 'package:stats':
##
##     cov, smooth, var
```

```
# Compute predicted probabilities on training data
m1_prob <- predict(bagging_1, finaldata_test, type = "prob")[,2]

# Compute AUC metrics for cv_model1,2 and 3
perf1 <- prediction(m1_prob,finaldata_test$Failure.binary) %>%
  performance(measure = "tpr", x.measure = "fpr")

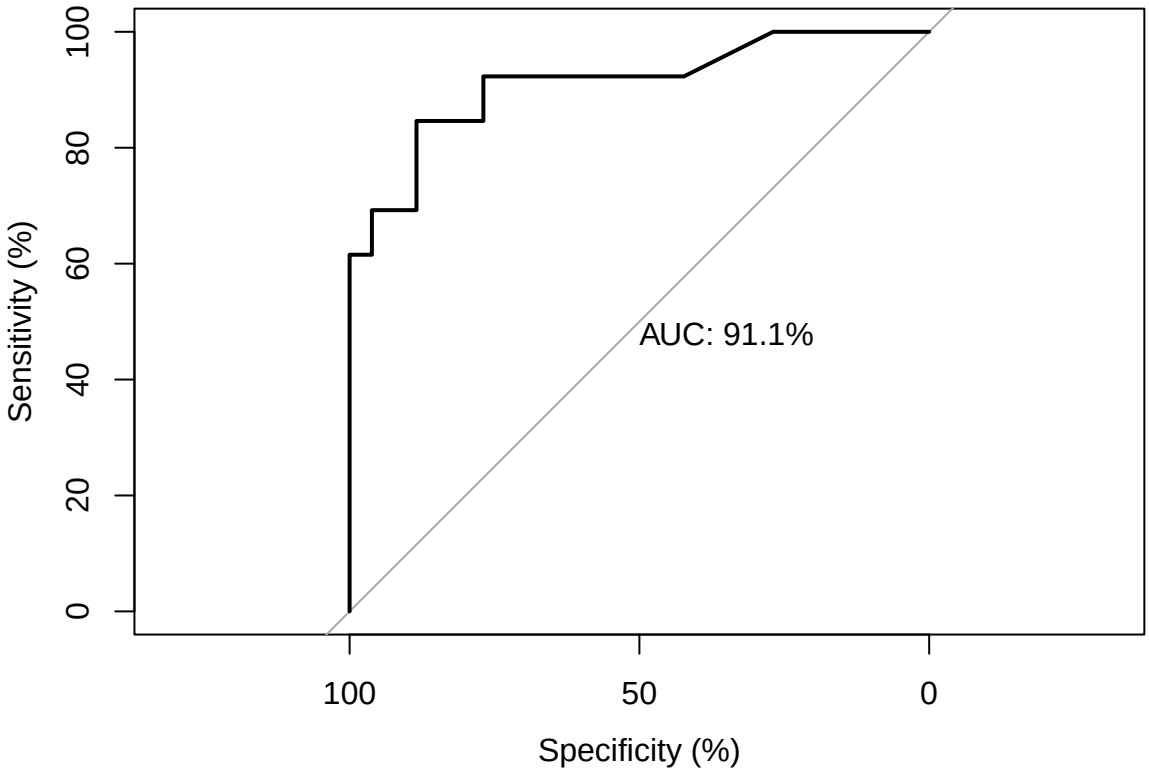

# Plot ROC curves for cv_model1,2 and 3
plot(perf1, col = "black", lty = 2)
```




```
# ROC plot for training data
roc( finaldata_test$Failure.binary ~ m1_prob, plot=TRUE, legacy.axes=FALSE,
    percent=TRUE, col="black", lwd=2, print.auc=TRUE)
```

```
## Setting levels: control = 0, case = 1
```

```
## Setting direction: controls < cases
```



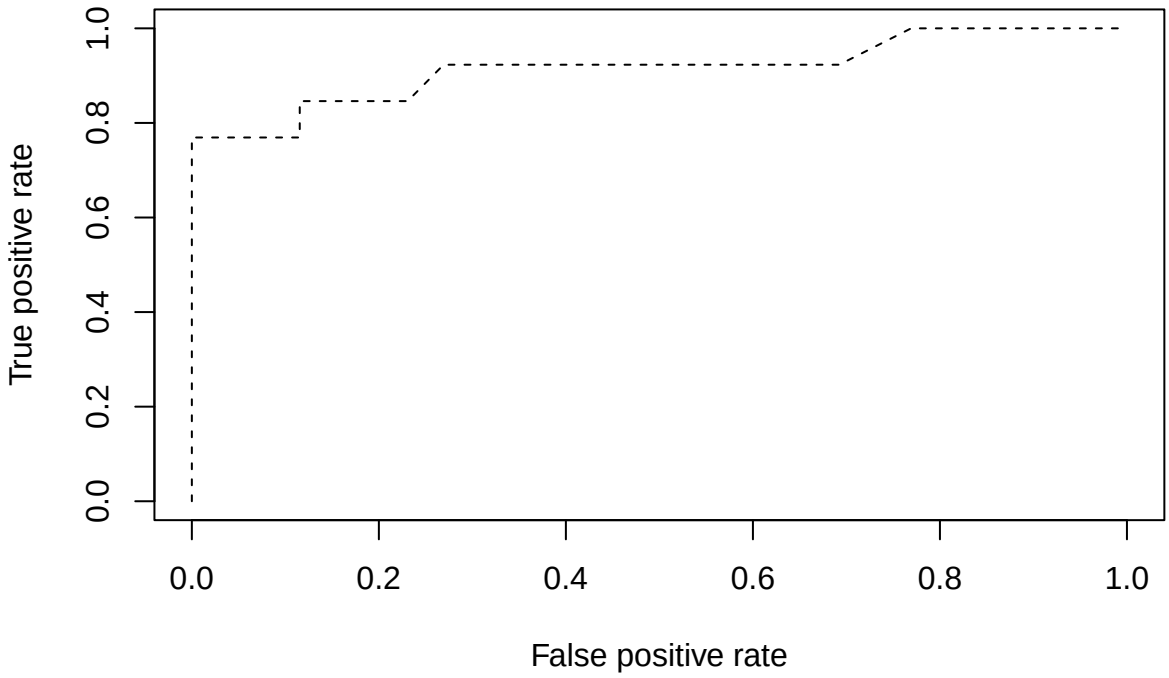

```
##
## Call:
## roc.formula(formula = finaldata_test$Failure.binary ~ m1_prob,     plot = TRUE, legacy.axes = FALSE,
##
## Data: m1_prob in 26 controls (finaldata_test$Failure.binary 0) < 13 cases (finaldata_test$Failure.bi
## Area under the curve: 91.12%
```

Testing our model bagging_1 to the testing set is helpful to determine the performance of our model and its sensitivity and specificity. The model has an AUC of 91.1%, which means it is a better model with 91.1% of the time the model will correctly clasify a random case.

```
# Compute predicted probabilities on training data
m1_prob <- predict(bagging_2, finaldata_test, type = "prob")[,2]

# Compute AUC metrics for cv_model1,2 and 3
perf1 <- prediction(m1_prob,finaldata_test$Failure.binary) %>%
  performance(measure = "tpr", x.measure = "fpr")

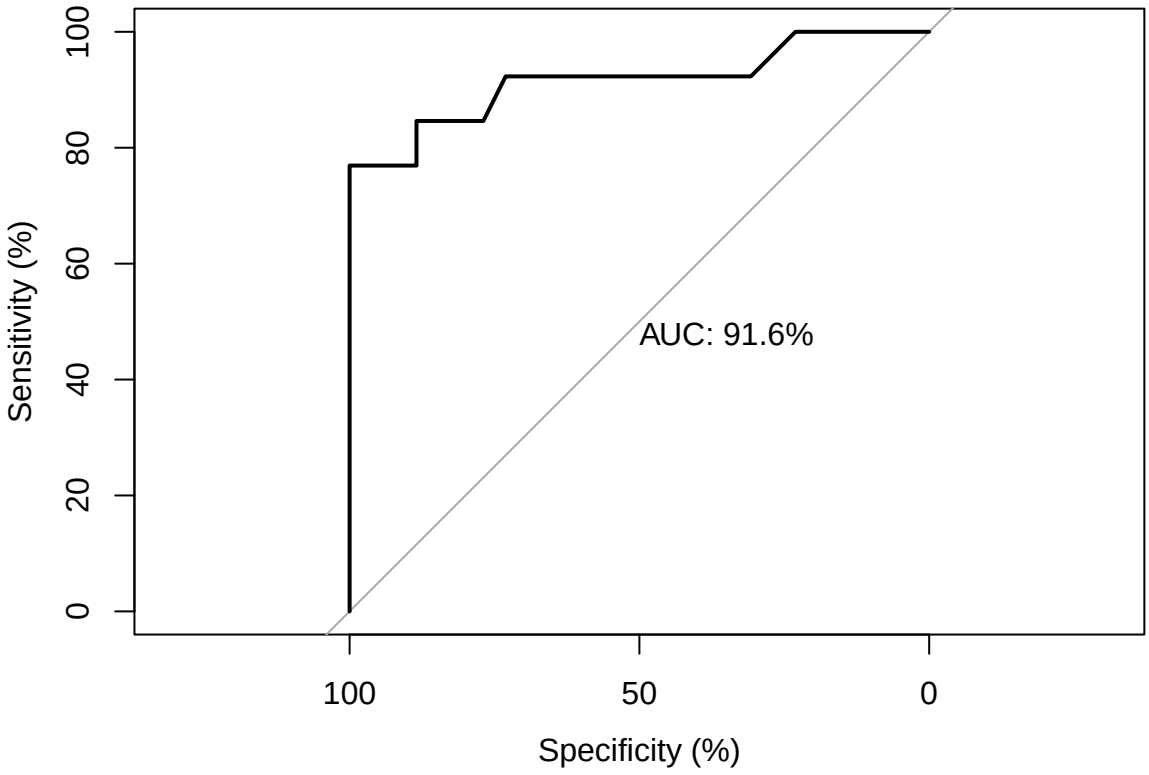

# Plot ROC curves for cv_model1,2 and 3
plot(perf1, col = "black", lty = 2)
```




```
# ROC plot for training data
roc( finaldata_test$Failure.binary ~ m1_prob, plot=TRUE, legacy.axes=FALSE,
    percent=TRUE, col="black", lwd=2, print.auc=TRUE)
```

```
## Setting levels: control = 0, case = 1
```

```
## Setting direction: controls < cases
```




```
##
## Call:
## roc.formula(formula = finaldata_test$Failure.binary ~ m1_prob,     plot = TRUE, legacy.axes = FALSE,
##
## Data: m1_prob in 26 controls (finaldata_test$Failure.binary 0) < 13 cases (finaldata_test$Failure.bi
## Area under the curve: 91.57%
```

Plotting the performance of the model bagging_2 will help us to tell how our model performed in predicting the target variable (Failure.binary). We test the performance of the model on the training set and found out that the model performed well on our testing set with 0.5% higher than the AUC of previous model, thus we can conclude that model bagging_2 is our final model in bagging.

Checking it on confusion matrix,

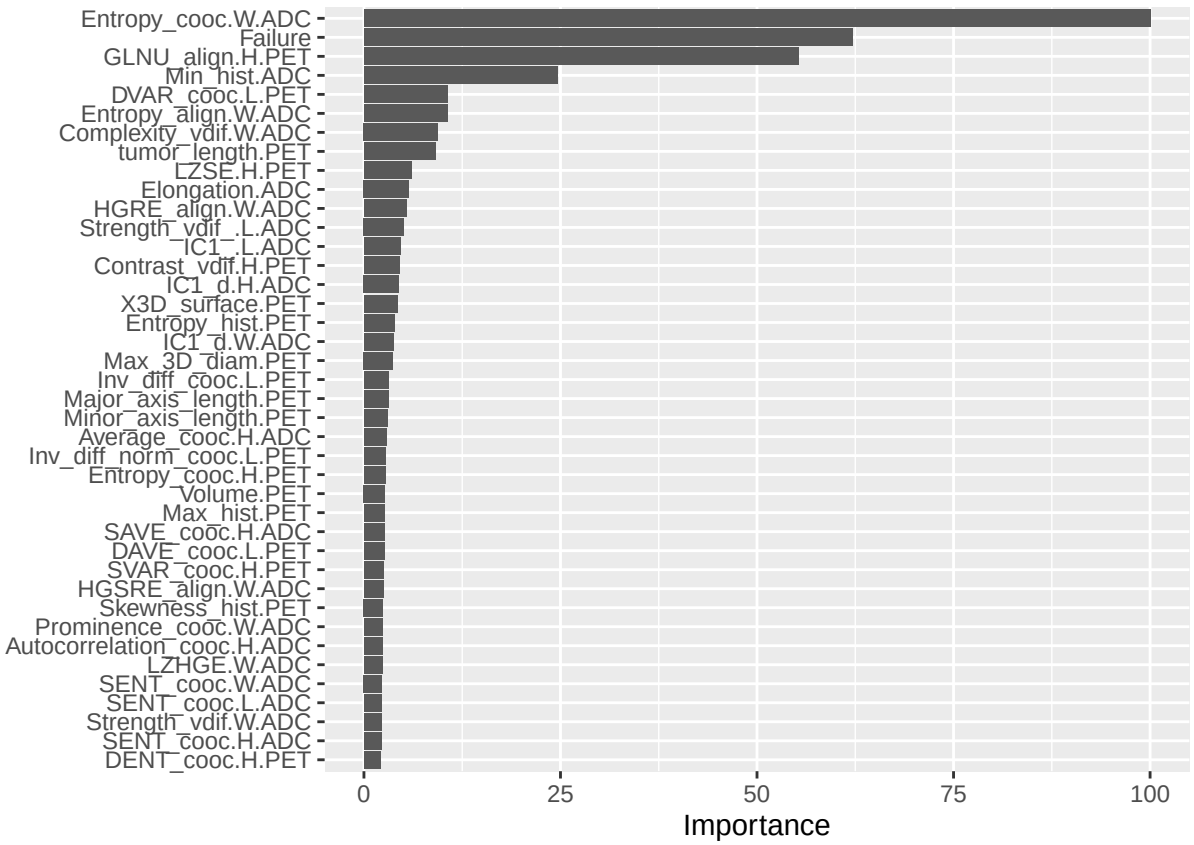
```
predictions = predict(bagging_2, newdata = finaldata_test)
confusionMatrix(data = finaldata_test$Failure.binary,predictions )
```

```
## Confusion Matrix and Statistics
##
##           Reference
## Prediction  0  1
##          0 23  3
##          1  2 11
##
##                Accuracy : 0.8718
##                  95% CI : (0.7257, 0.957)
##     No Information Rate : 0.641
##     P-Value [Acc > NIR] : 0.001224
```

```
##
##                   Kappa : 0.717
##
##  Mcnemar's Test P-Value : 1.000000
##
##             Sensitivity : 0.9200
##             Specificity : 0.7857
##          Pos Pred Value : 0.8846
##          Neg Pred Value : 0.8462
##              Prevalence : 0.6410
##          Detection Rate : 0.5897
##    Detection Prevalence : 0.6667
##       Balanced Accuracy : 0.8529
##
##        'Positive' Class : 0
##
```

According to confusion matrix, 23 of the predicted `0` is correctly classified by the model and 11 of the predicted `1` are classified correctly by the model only 5 were misclassified.

```
vip::vip(bagging_2, num_features = 40)
```



Based on model bagging_2, Entropy_cooc.W.ADC, Failure and GLNU_align.H.PET are the top important variables that helps the model to make an accurate prediction on the classification of any random case inputted in the model.

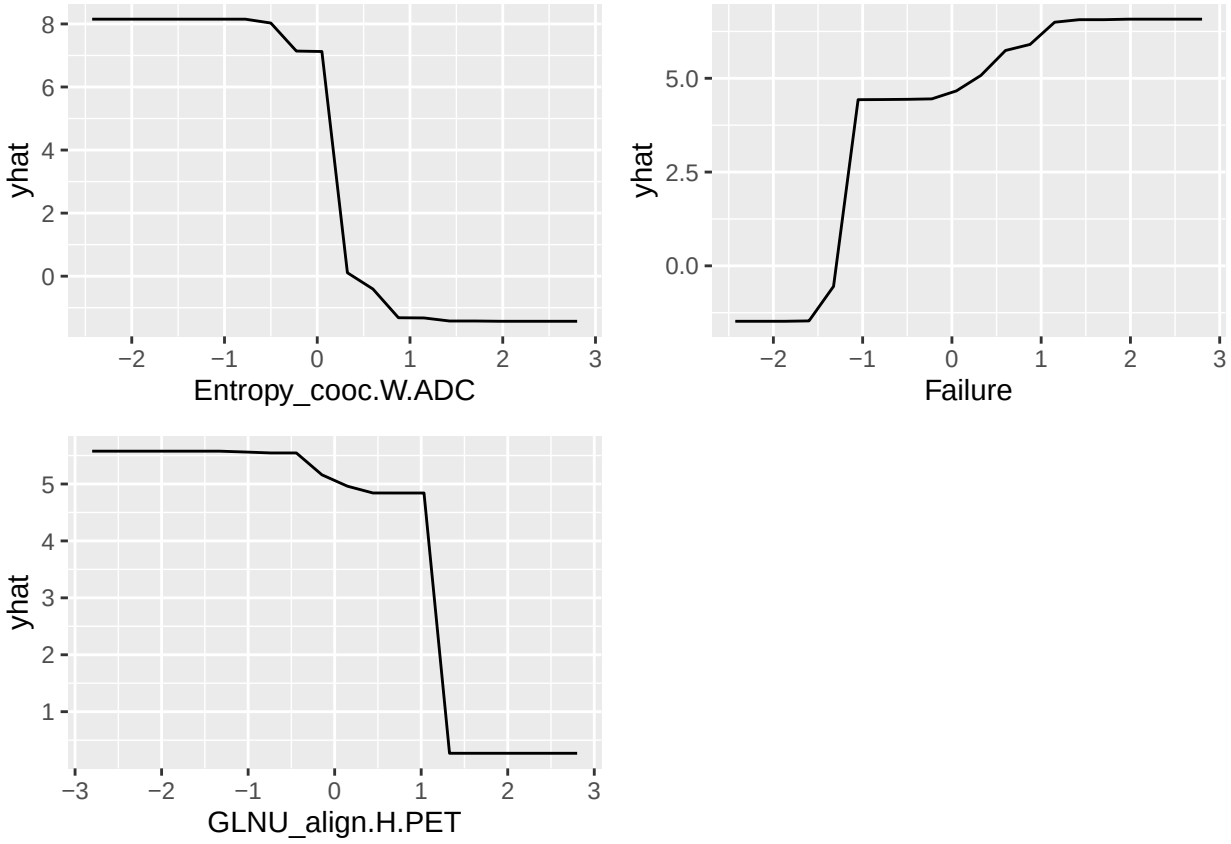
```
p1 <- pdp::partial(
  bagging_2,
```

```
  pred.var = "Entropy_cooc.W.ADC",
  grid.resolution = 20
  ) %>%
  autoplot()

p2 <- pdp::partial(
  bagging_2,
  pred.var = "Failure",
  grid.resolution = 20
  ) %>%
  autoplot()


p3 = pdp::partial(
  bagging_2,
  pred.var = "GLNU_align.H.PET",
  grid.resolution = 20
  ) %>%
  autoplot()


gridExtra::grid.arrange(p1, p2, p3, nrow = 2)
```



The partial dependence plot shows the dependence between the Failure.binary response/target variable and these top 3 feature variables (i.e. Failure, GLNU_align.H.PET and Entropy-cooc.W.ADC. of interest. As shown in PDP above, lower Entropy.cooc.W.ADC implies that Failure.binary is more likely to be 1, the

higher the Entropy_cooc.W.ADC the more likely the `Failure.binary` to be 0,and the lower the failure the more likely the Final.binary to be 0.