

Generalized Boosted Regression Model (GBM)

Replication-based stagewise additive modeling (RSAM)

EGG data-based experiments

Article: Lizbeth Naranjo, Carlos J. Perez, Daniel F. Merino (2025). A data ensemble-based approach for detecting vocal disorders using replicated acoustic biomarkers from electroglottography. *Sensing and Bio-Sensing Research Journal*, vol, num, pages.

```
library(tidyverse)
library(gbm)
## change the address where the file will be saved
address = "~/Documents/GitHub/"
setwd("~/Documents/GitHub/")
```

EGG data-based experiments

```
## Comment or uncomment the options: EGG-a, EGG-i, EGG-u
```

```
## EGG-a
datos2 <- read.csv(paste0(address,"a_egg_saarbrucken.csv"),
                  sep = ";",header=TRUE, dec=",")

## name of the files to save results
archivo = "RSAM_crossval_strata_allvar_GBM_Saarbrucken_egg_a"
```

```
## EGG-i
## datos2 <- read.csv(paste0(address,"i_egg_saarbrucken.csv"),
##                  sep = ";",header=TRUE, dec=",")

## name of the files to save results
## archivo = "RSAM_crossval_strata_allvar_GBM_Saarbrucken_egg_i"
```

```
## EGG-u
## datos2 <- read.csv(paste0(address,"u_egg_saarbrucken.csv"),
##                  sep = ";",header=TRUE, dec=",")

## name of the files to save results
## archivo = "RSAM_crossval_strata_allvar_GBM_Saarbrucken_egg_u"
```

```
dim(datos2)
```

```
[1] 675 36
```

```
summary(datos2)
```

ID_fact	status_fact	SEX	JITTER
Min. : 1.0	Min. :0	Min. :0.0000	Min. : 0.11
1st Qu.:169.5	1st Qu.:0	1st Qu.:0.0000	1st Qu.: 0.49
Median :338.0	Median :1	Median :0.0000	Median : 5.52
Mean :338.0	Mean :1	Mean :0.4133	Mean : 18.90
3rd Qu.:506.5	3rd Qu.:2	3rd Qu.:1.0000	3rd Qu.: 25.89
Max. :675.0	Max. :2	Max. :1.0000	Max. :281.41
SHIMMER	CPP	D2	FZCF
Min. :0.01000	Min. :12.26	Min. : 2.480	Min. : 2.00
1st Qu.:0.03000	1st Qu.:21.08	1st Qu.: 4.130	1st Qu.: 5.00
Median :0.04000	Median :24.60	Median : 5.100	Median : 9.00
Mean :0.05887	Mean :24.26	Mean : 5.666	Mean : 45.86
3rd Qu.:0.08000	3rd Qu.:27.36	3rd Qu.: 6.795	3rd Qu.: 20.00
Max. :0.37000	Max. :35.94	Max. :27.380	Max. :5323.00
GENE	HNHR	HURST	LZ
Min. :0.3800	Min. : -4.40	Min. :0.0400	Min. : 19.00
1st Qu.:0.6300	1st Qu.:14.07	1st Qu.:0.4200	1st Qu.: 55.50
Median :0.7700	Median :18.40	Median :0.6300	Median : 83.00
Mean :0.9037	Mean :17.38	Mean :0.7015	Mean : 86.81
3rd Qu.:1.0000	3rd Qu.:21.66	3rd Qu.:0.9100	3rd Qu.:107.00
Max. :4.6300	Max. :32.35	Max. :1.7800	Max. :304.00
MFCC0	MFCC1	MFCC2	MFCC3
Min. : -2.6200	Min. : -23.850	Min. : -47.190	Min. : -49.37
1st Qu.: -0.5700	1st Qu.: 3.300	1st Qu.: -22.285	1st Qu.: -24.59
Median : 0.1700	Median : 9.150	Median : -9.750	Median : -15.21
Mean : 0.1388	Mean : 8.767	Mean : -9.716	Mean : -14.79
3rd Qu.: 0.8600	3rd Qu.: 14.980	3rd Qu.: 2.915	3rd Qu.: -4.03
Max. : 3.0700	Max. : 30.920	Max. : 23.390	Max. : 19.56
MFCC4	MFCC5	MFCC6	MFCC7
Min. : -61.070	Min. : -67.210	Min. : -62.600	Min. : -39.460
1st Qu.: -21.130	1st Qu.: -12.535	1st Qu.: -16.040	1st Qu.: -11.790
Median : -8.770	Median : -2.020	Median : -3.600	Median : -2.960
Mean : -9.488	Mean : -3.153	Mean : -4.740	Mean : -3.146
3rd Qu.: 2.400	3rd Qu.: 7.065	3rd Qu.: 5.175	3rd Qu.: 4.690
Max. : 38.080	Max. : 36.640	Max. : 46.700	Max. : 40.120
MFCC8	MFCC9	MFCC10	MFCC11
Min. : -44.230	Min. : -35.240	Min. : -41.950	Min. : -41.300
1st Qu.: -14.685	1st Qu.: -12.990	1st Qu.: -12.415	1st Qu.: -11.705
Median : -5.340	Median : -4.580	Median : -4.830	Median : -4.040
Mean : -5.353	Mean : -3.993	Mean : -4.637	Mean : -4.130
3rd Qu.: 2.660	3rd Qu.: 3.420	3rd Qu.: 2.760	3rd Qu.: 2.755
Max. : 49.090	Max. : 49.370	Max. : 41.220	Max. : 36.180
MFCC12	PERMUTATION	PPE	SHANNON
Min. : -36.840	Min. :1.150	Min. :0.1900	Min. :11.79
1st Qu.: -10.890	1st Qu.:1.640	1st Qu.:0.5300	1st Qu.:12.12
Median : -3.390	Median :1.810	Median :0.5500	Median :12.16
Mean : -2.904	Mean :1.827	Mean :0.5312	Mean :12.15

3rd Qu.: 3.935	3rd Qu.:1.990	3rd Qu.:0.5700	3rd Qu.:12.19
Max. : 31.870	Max. :2.550	Max. :0.5700	Max. :12.26
ZCR	energyentropy	spectralcentroid	spectralspread
Min. :0.01000	Min. :2.540	Min. :0.0600	Min. :0.1100
1st Qu.:0.04000	1st Qu.:3.230	1st Qu.:0.1200	1st Qu.:0.1600
Median :0.07000	Median :3.300	Median :0.1500	Median :0.1800
Mean :0.07056	Mean :3.248	Mean :0.1545	Mean :0.1805
3rd Qu.:0.09000	3rd Qu.:3.310	3rd Qu.:0.1800	3rd Qu.:0.2000
Max. :0.23000	Max. :3.320	Max. :0.3200	Max. :0.2800
spectralentropy	spectralrolloff	RPDE	rep
Min. :0.0100	Min. :0.0100	Min. :0.1000	Min. :1
1st Qu.:0.1900	1st Qu.:0.0700	1st Qu.:0.2700	1st Qu.:1
Median :0.6600	Median :0.1100	Median :0.3500	Median :2
Mean :0.6867	Mean :0.1178	Mean :0.3948	Mean :2
3rd Qu.:1.0700	3rd Qu.:0.1600	3rd Qu.:0.4950	3rd Qu.:3
Max. :1.9100	Max. :0.4500	Max. :0.9100	Max. :3

```
head(datos2)
```

	ID_fact	status_fact	SEX	JITTER	SHIMMER	CPP	D2	FZCF	GNE	HNR	HURST	LZ
1	1		0	0	6.76	0.06	28.26	3.71	23	0.67	18.96	1.11 44
2	2		0	0	0.31	0.06	23.32	3.40	48	0.47	17.76	1.58 36
3	3		0	0	0.19	0.04	23.55	3.68	58	0.46	21.86	1.70 24
4	4		0	0	0.45	0.01	33.64	2.96	37	0.42	25.78	1.45 27
5	5		0	0	0.39	0.07	26.95	2.66	50	0.39	21.44	1.63 29
6	6		0	0	0.34	0.04	35.36	3.03	35	0.44	28.32	1.45 28
	MFCC0	MFCC1	MFCC2	MFCC3	MFCC4	MFCC5	MFCC6	MFCC7	MFCC8	MFCC9	MFCC10	MFCC11
1	-0.75	11.11	-0.88	-4.03	4.01	-0.10	-5.14	-4.07	-7.72	-9.94	-12.93	-13.10
2	-1.16	-0.60	12.22	4.06	5.84	3.35	6.71	1.68	2.86	3.01	1.88	1.35
3	-1.70	2.81	15.53	7.78	7.22	8.27	3.33	3.90	4.74	6.15	1.74	2.75
4	-1.00	11.34	5.69	1.20	1.84	8.61	-0.60	4.50	0.59	2.95	-0.09	1.14
5	-1.91	11.97	7.29	7.30	7.14	4.34	6.10	3.49	2.89	2.92	2.73	2.47
6	-1.43	6.93	3.04	11.37	1.89	1.65	3.27	5.75	-0.33	4.49	-1.93	2.00
	MFCC12	PERMUTATION	PPE	SHANNON	ZCR	energyentropy	spectralcentroid					
1	-10.64		1.94	0.40	12.18	0.02	3.30 0.12					
2	2.93		2.53	0.57	12.20	0.01	3.21 0.13					
3	2.26		2.41	0.53	12.16	0.01	3.26 0.12					
4	-0.36		1.34	0.55	12.18	0.01	3.28 0.10					
5	2.88		1.76	0.57	12.20	0.01	3.23 0.09					
6	-1.05		1.38	0.55	12.05	0.01	3.29 0.13					
	spectralspread	spectralentropy	spectralrolloff	RPDE	rep							
1	0.19		0.16	0.04	0.50 1							
2	0.23		0.07	0.02	0.57 2							
3	0.21		0.06	0.02	0.43 3							
4	0.18		0.07	0.03	0.41 1							
5	0.16		0.03	0.01	0.47 2							
6	0.20		0.09	0.03	0.28 3							

Re-Scale explanatory variables

```
## Scale the variables
datos2 <- as.data.frame(datos2)
datos2$STATUS_fact = as.factor(as.numeric(factor(datos2$status_fact)))

table(datos2$STATUS_fact)
```

```
 1    2    3
225 225 225
```

```
datos <- transform(datos2,
sJITTER= scale(JITTER), sSHIMMER= scale(SHIMMER), sCPP= scale(CPP),
sD2= scale(D2), sFZCF= scale(FZCF), sGNE= scale(GNE),
sHNR= scale(HNR), sHURST= scale(HURST), sLZ= scale(LZ),
sMFCC0= scale(MFCC0),
sMFCC1= scale(MFCC1), sMFCC2= scale(MFCC2), sMFCC3= scale(MFCC3),
sMFCC4= scale(MFCC4), sMFCC5= scale(MFCC5), sMFCC6= scale(MFCC6),
sMFCC7= scale(MFCC7), sMFCC8= scale(MFCC8), sMFCC9= scale(MFCC9),
sMFCC10= scale(MFCC10), sMFCC11= scale(MFCC11), sMFCC12= scale(MFCC12),
sPERMUTATION= scale(PERMUTATION), sPPE= scale(PPE), sSHANNON= scale(SHANNON),
sZCR= scale(ZCR),
senenergyentropy= scale(energyentropy), sspectralcentroid= scale(spectralcentroid),
sspectralspread= scale(spectralspread), sspectralentropy= scale(spectralentropy),
sspectralrolloff= scale(spectralrolloff), sRPDE= scale(RPDE))

datos$ID_fact = rep(1:225,each=3)

dim(datos)
```

```
[1] 675  69
```

```
## data set
trainc <- datos %>% select(
sJITTER, sSHIMMER, sCPP, sD2, sFZCF,
sGNE, sHNR, sHURST, sLZ, sMFCC0,
sMFCC1, sMFCC2, sMFCC3, sMFCC4, sMFCC5,
sMFCC6, sMFCC7, sMFCC8, sMFCC9, sMFCC10,
sMFCC11, sMFCC12,
sPERMUTATION, sPPE, sSHANNON, sZCR,
senenergyentropy, sspectralcentroid, sspectralspread,
sspectralentropy, sspectralrolloff, sRPDE,
STATUS_fact,SEX, rep,ID_fact)
```

Crossvalidation

Training and testing data subsets

```
## Select data: 75% training & 25% testing stratified per category
SIM = 100  ## repeat N times the cross-validation process
N = 225  ## sample size
Nfit = 168  ## sample size for training subset
Ntest = 57  ## sample size for testing subset
Ncat = 75  ## sample size per category
Ncatfit = 56  ## training per category
Ncattest = 19  ## testing per category
FIT <- matrix(0,SIM,Nfit)  ## training subsets
TEST <- matrix(0,SIM,Ntest)  ## testing subsets

categoria = trainc %>% filter(rep==1) %>% select(STATUS_fact)
categoria = as.numeric(categoria$STATUS_fact)
id = 1:N
set.seed(12345)
for(si in 1:SIM){
  for(j in 1:3){
    idcat = id[categoria==j]  ## stratified per category j
    ran0 = sample(idcat, size=Ncatfit, replace=FALSE)

    FIT[si,(j-1)*Ncatfit+1:Ncatfit] <- sort(ran0)
    TEST[si,(j-1)*Ncattest+1:Ncattest] <- setdiff(idcat,ran0)
  } }
```

Classification metrics for models predicting nominal outcomes

```
## Functions to compute classification metrics
## Ytrue = true response variable
## Ypred = predicted outcome
## cat = category
## TP = true positive
## TN = true negative
## FP = false positive
## FN = false negative

## Function to compute the precision per class=cat
fn_precision_class <- function(Ytrue,Ypred,cat){
  TP = sum(Ypred[Ytrue==cat]==cat)
  FP = sum(Ypred[Ytrue!=cat]==cat)
  precision = TP/(TP+FP)
  return(precision)
}

## Function to compute the recall per class=cat
fn_recall_class <- function(Ytrue,Ypred,cat){ ## cat==category
  TP = sum(Ypred[Ytrue==cat]==cat)
  FN = sum(Ypred[Ytrue==cat]!=cat)
  recall = TP/(TP+FN)
  return(recall)
}

## Function to compute the F1-score per class=cat
fn_f1score_class <- function(Ytrue,Ypred,cat){ ## cat==category
  TP = sum(Ypred[Ytrue==cat]==cat)
  FP = sum(Ypred[Ytrue!=cat]==cat)
  FN = sum(Ypred[Ytrue==cat]!=cat)
  precision = TP/(TP+FP)
  recall = TP/(TP+FN)
  f1score = 2*(precision*recall)/(precision+recall)
  return(f1score)
}

## To save classification metrics
## Fitxxx: metric for training subset. Testxxx: metric for testing subset
FitAccuracy = TestAccuracy <- array(NA,dim=c(SIM,4)) ## Accuracy Rate
FitPrecisionClass = TestPrecisionClass <- array(NA,dim=c(SIM,4,3)) ## Precision per class
FitRecallClass = TestRecallClass <- array(NA,dim=c(SIM,4,3)) ## Recall per class
FitF1ScoreClass = TestF1ScoreClass <- array(NA,dim=c(SIM,4,3)) ## F1-score per class
FitPrecisionMacroAve = TestPrecisionMacroAve <- array(NA,dim=c(SIM,4)) ## Precision Macro Average
FitRecallMacroAve = TestRecallMacroAve <- array(NA,dim=c(SIM,4)) ## Recall Macro Average
FitF1ScoreMacroAve = TestF1ScoreMacroAve <- array(NA,dim=c(SIM,4)) ## F1-score Macro Average
```

Model estimation

```
##-----
for(sim in 1:SIM){  ## BEGIN sim
##-----
my_fit = FIT[sim,]  ## training subset
my_test = TEST[sim,]  ## testing subset

## Training data subset
train1 <- trainc %>% filter(ID_fact%in%my_fit, rep==1)  ## repetition=1
train2 <- trainc %>% filter(ID_fact%in%my_fit, rep==2)  ## repetition=2
train3 <- trainc %>% filter(ID_fact%in%my_fit, rep==3)  ## repetition=3

Yc = train1$STATUS_fact  ## categorical response variable for training
n = length(Yc)
G = 3 # classes

## Testing data subset
test1 <- trainc %>% filter(ID_fact%in%my_test, rep==1)  ## repetition=1
test2 <- trainc %>% filter(ID_fact%in%my_test, rep==2)  ## repetition=2
test3 <- trainc %>% filter(ID_fact%in%my_test, rep==3)  ## repetition=3

Yc.new = test1$STATUS_fact  ## categorical response variable for testing
n.new = length(Yc.new)

## Delete variables which are not used
train1 <- train1 %>% select(-c(SEX,rep,ID_fact))
train2 <- train2 %>% select(-c(SEX,rep,ID_fact))
train3 <- train3 %>% select(-c(SEX,rep,ID_fact))
test1 <- test1 %>% select(-c(SEX,rep,ID_fact,STATUS_fact))
test2 <- test2 %>% select(-c(SEX,rep,ID_fact,STATUS_fact))
test3 <- test3 %>% select(-c(SEX,rep,ID_fact,STATUS_fact))

##-----
## Algorithm RSAM
## Replication-based stagewise additive modeling
##-----

## Algo1: Initialize the observation weights  $w_i=1/n$ ,  $i=1,\dots,n$ 
w1 = rep(1/n,n)

## Algo2: BEGIN for replication  $j=1$  to  $J$  do:

## REPLICATION  $j=1$ :
## Algo3: Fit a classifier  $T(x_j,z)$  to the training data using weights  $w_i$ 
mod1 <- gbm(
  formula = STATUS_fact ~ . ,
  distribution = "multinomial" ,
  weights = w1 ,
  data = train1 ,
  n.trees = 100 ,
  interaction.depth = 5,
  shrinkage = 0.3,
```

```

bag.fraction = 0.5,
train.fraction = 1.0,
n.cores = NULL # will use all cores by default
)
## summary(mod1)

## Predictions
pred1.vgam <- predict(mod1, newdata=train1, n.trees=100, "response")
pred1 <- apply(pred1.vgam,1,which.max)

## Algo4: Compute $err = \sum wi I[Y \neq T(xj,z)] / \sum wi$
err1 <- (sum(wi1*(Yc!=pred1))) / sum(wi1)
## Algo5: Compute $alpha = \log (1-err)/err + \log(G-1)$
alp1 <- log((1-err1)/err1) + log(G-1)
alp1 <- ifelse(is.finite(alp1), alp1, log(G-1))
## Algo6: Set wi = wi* exp(alpha*I[Y \neq T(xj,z)])
wi2 = wi1*exp(alp1*(Yc!=pred1))
## Algo7: Re-normalize wi
wi2 = c(wi2/sum(wi2))

##-----
## REPLICATION j=2:
## Algo3: Fit a classifier $T(xj,z)$ to the training data using weights $wi$
mod2 <- gbm(
  formula = STATUS_fact ~ . ,
  distribution = "multinomial" ,
  weights = wi2 ,
  data = train2 ,
  n.trees = 100 ,
  interaction.depth = 5,
  shrinkage = 0.3,
  bag.fraction = 0.5,
  train.fraction = 1.0,
  n.cores = NULL # will use all cores by default
)
## summary(mod2)

## Predictions
pred2.vgam <- predict(mod2, newdata=train2, n.trees=100, "response")
pred2 <- apply(pred2.vgam,1,which.max)

## Algo4: Compute $err = \sum wi I[Y \neq T(xj,z)] / \sum wi$
err2 <- (sum(wi2*(Yc!=pred2))) / sum(wi2)
## Algo5: Compute $alpha = \log (1-err)/err + \log(G-1)$
alp2 <- log((1-err2)/err2) + log(G-1)
alp2 <- ifelse(is.finite(alp2), alp2, log(G-1))
## Algo6: Set wi = wi* exp(alpha*I[Y \neq T(xj,z)])
wi3 = wi2*exp(alp2*(Yc!=pred2))
## Algo7: Re-normalize wi
wi3 = c(wi3/sum(wi3))

##-----
## REPLICATION j=3:

```



```

## Algo3: Fit a classifier  $T(x_j, z)$  to the training data using weights  $w_i$ 
mod3 <- gbm(
  formula = STATUS_fact ~ . ,
  distribution = "multinomial" ,
  weights = wi3 ,
  data = train3 ,
  n.trees = 100 ,
  interaction.depth = 5,
  shrinkage = 0.3,
  bag.fraction = 0.5,
  train.fraction = 1.0,
  n.cores = NULL # will use all cores by default
)
## summary(mod3)

## Predictions
pred3.vgam <- predict(mod3, newdata=train3, n.trees=100, "response")
pred3 <- apply(pred3.vgam, 1, which.max)

## Algo4: Compute  $\text{err} = \sum w_i I[Y \neq T(x_j, z)] / \sum w_i$ 
err3 <- (sum(wi3*(Yc!=pred3))) / sum(wi3)
## Algo5: Compute  $\alpha = \log(1-\text{err})/\text{err} + \log(G-1)$ 
alp3 <- log((1-err3)/err3) + log(G-1)
alp3 <- ifelse(is.finite(alp3), alp3, log(G-1))
## Algo6: Set  $w_i = w_i \exp(\alpha I[Y \neq T(x_j, z)])$ 
wi4 = wi3*exp(alp3*(Yc!=pred3))
## Algo7: Re-normalize  $w_i$ 
wi4 = c(wi4/sum(wi4))

## Algo8: End for replication  $j=1$  to  $J$ 
##-----

## Algo9: Output  $T^*(x, z) = \arg \max_G \sum_j \alpha I[T(x_j, z)=G]$ 

pred = cbind(pred1, pred2, pred3)
alpha = c(alp1, alp2, alp3)

argclase = matrix(NA, n, 3)
clase = rep(NA, n)
for(i in 1:n){
  argclase[i, 1] = sum(alpha*(pred[i,]==1))
  argclase[i, 2] = sum(alpha*(pred[i,]==2))
  argclase[i, 3] = sum(alpha*(pred[i,]==3))
  clase[i] = which(argclase[i,]==max(argclase[i,]))
}
##-----

## Predict new subjects for testing subsets

pred1.new.vgam <- predict(mod1, newdata = test1, n.trees=100, "response")
pred2.new.vgam <- predict(mod2, newdata = test2, n.trees=100, "response")
pred3.new.vgam <- predict(mod3, newdata = test3, n.trees=100, "response")
pred1.new <- apply(pred1.new.vgam, 1, which.max)
pred2.new <- apply(pred2.new.vgam, 1, which.max)

```

```

pred3.new <- apply(pred3.new.vgam,1,which.max)

pred.new = cbind(pred1.new,pred2.new,pred3.new)

argclass.new = matrix(NA,n.new,3)
class.new = rep(NA,n.new)
for(i in 1:n.new){
  argclass.new[i,1] = sum(alpha*(pred.new[i,]==1))
  argclass.new[i,2] = sum(alpha*(pred.new[i,]==2))
  argclass.new[i,3] = sum(alpha*(pred.new[i,]==3))
  class.new[i] = which(argclass.new[i,]==max(argclass.new[i,]))
}
##-----
## End RSAM
##-----
## Classification Metrics for models predicting nominal outcomes

## Accuracy Rate
FitAccuracy[sim,] = c(sum(Yc==pred1)/n,
                      sum(Yc==pred2)/n,
                      sum(Yc==pred3)/n,
                      sum(Yc==class)/n)

TestAccuracy[sim,] = c(sum(Yc.new==pred1.new)/n.new,
                      sum(Yc.new==pred2.new)/n.new,
                      sum(Yc.new==pred3.new)/n.new,
                      sum(Yc.new==class.new)/n.new)

## Precision
for(cate in 1:3){
  FitPrecisionClass[sim,1, cate] = fn_precision_class(Yc, pred1, cate)
  FitPrecisionClass[sim,2, cate] = fn_precision_class(Yc, pred2, cate)
  FitPrecisionClass[sim,3, cate] = fn_precision_class(Yc, pred3, cate)
  FitPrecisionClass[sim,4, cate] = fn_precision_class(Yc, class, cate)

  TestPrecisionClass[sim,1, cate] = fn_precision_class(Yc.new, pred1.new, cate)
  TestPrecisionClass[sim,2, cate] = fn_precision_class(Yc.new, pred2.new, cate)
  TestPrecisionClass[sim,3, cate] = fn_precision_class(Yc.new, pred3.new, cate)
  TestPrecisionClass[sim,4, cate] = fn_precision_class(Yc.new, class.new, cate)
}
for(rep in 1:4){
  FitPrecisionMacroAve[sim, rep] = mean(FitPrecisionClass[sim, rep,])
  TestPrecisionMacroAve[sim,rep] = mean(TestPrecisionClass[sim,rep,])
}

## Recall
for(cate in 1:3){
  FitRecallClass[sim,1, cate] = fn_recall_class(Yc, pred1, cate)
  FitRecallClass[sim,2, cate] = fn_recall_class(Yc, pred2, cate)
  FitRecallClass[sim,3, cate] = fn_recall_class(Yc, pred3, cate)
  FitRecallClass[sim,4, cate] = fn_recall_class(Yc, class, cate)

  TestRecallClass[sim,1, cate] = fn_recall_class(Yc.new, pred1.new, cate)

```

```

TestRecallClass[sim,2, cate] = fn_recall_class(Yc.new, pred2.new, cate)
TestRecallClass[sim,3, cate] = fn_recall_class(Yc.new, pred3.new, cate)
TestRecallClass[sim,4, cate] = fn_recall_class(Yc.new, clase.new, cate)
}
for(rep in 1:4){
  FitRecallMacroAve[sim, rep] = mean(FitRecallClass[sim, rep,])
  TestRecallMacroAve[sim,rep] = mean(TestRecallClass[sim,rep,])
}

## F1-Score
for(cate in 1:3){
  FitF1ScoreClass[sim,1, cate]= fn_f1score_class(Yc, pred1, cate)
  FitF1ScoreClass[sim,2, cate]= fn_f1score_class(Yc, pred2, cate)
  FitF1ScoreClass[sim,3, cate]= fn_f1score_class(Yc, pred3, cate)
  FitF1ScoreClass[sim,4, cate]= fn_f1score_class(Yc, clase, cate)

  TestF1ScoreClass[sim,1, cate] = fn_f1score_class(Yc.new, pred1.new, cate)
  TestF1ScoreClass[sim,2, cate] = fn_f1score_class(Yc.new, pred2.new, cate)
  TestF1ScoreClass[sim,3, cate] = fn_f1score_class(Yc.new, pred3.new, cate)
  TestF1ScoreClass[sim,4, cate] = fn_f1score_class(Yc.new, clase.new, cate)
}
for(rep in 1:4){
  FitF1ScoreMacroAve[sim, rep] = mean(FitF1ScoreClass[sim, rep,])
  TestF1ScoreMacroAve[sim,rep] = mean(TestF1ScoreClass[sim,rep,])
}
##-----
}## END sim
##-----

```

Results

Accuracy Rate

```
columna = c("rep1","rep2","rep3","ensemble")
renglon = c("fit_mean","fit_sd","test_mean","test_sd")

summary(FitAccuracy)
```

```
##           V1           V2           V3           V4
## Min.      :1    Min.      :1    Min.      :1    Min.      :1
## 1st Qu.:1    1st Qu.:1    1st Qu.:1    1st Qu.:1
## Median :1    Median :1    Median :1    Median :1
## Mean      :1    Mean      :1    Mean      :1    Mean      :1
## 3rd Qu.:1    3rd Qu.:1    3rd Qu.:1    3rd Qu.:1
## Max.      :1    Max.      :1    Max.      :1    Max.      :1
```

```
apply(FitAccuracy,2,"sd")
```

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

```
summary(TestAccuracy)
```

```
##           V1           V2           V3           V4
## Min.      :0.4386    Min.      :0.4211    Min.      :0.4561    Min.      :0.4386
## 1st Qu.:0.5395    1st Qu.:0.5570    1st Qu.:0.5570    1st Qu.:0.5789
## Median :0.5789    Median :0.5965    Median :0.5965    Median :0.6316
## Mean      :0.5800    Mean      :0.5882    Mean      :0.5933    Mean      :0.6265
## 3rd Qu.:0.6316    3rd Qu.:0.6316    3rd Qu.:0.6316    3rd Qu.:0.6667
## Max.      :0.7193    Max.      :0.7193    Max.      :0.7368    Max.      :0.7544
```

```
apply(TestAccuracy,2,"sd")
```

```
## [1] 0.06366290 0.05465739 0.05748111 0.05769247
```

```
RESaccuracy <- rbind(apply(FitAccuracy,2,"mean"), apply(FitAccuracy,2,"sd"),
                    apply(TestAccuracy,2,"mean"),apply(TestAccuracy,2,"sd"))
colnames(RESaccuracy) = columna
rownames(RESaccuracy) = renglon
write.csv(RESaccuracy, file=paste0(archivo,"_accuracy",".csv"))
```

Precision Macro Average

```
summary(FitPrecisionMacroAve)
```

```
##           V1           V2           V3           V4
## Min.      :1   Min.      :1   Min.      :1   Min.      :1
## 1st Qu.:1   1st Qu.:1   1st Qu.:1   1st Qu.:1
## Median :1   Median :1   Median :1   Median :1
## Mean      :1   Mean      :1   Mean      :1   Mean      :1
## 3rd Qu.:1   3rd Qu.:1   3rd Qu.:1   3rd Qu.:1
## Max.      :1   Max.      :1   Max.      :1   Max.      :1
```

```
apply(FitPrecisionMacroAve,2,"sd")
```

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

```
summary(TestPrecisionMacroAve)
```

```
##           V1           V2           V3           V4
## Min.      :0.4384   Min.      :0.4369   Min.      :0.4579   Min.      :0.4392
## 1st Qu.:0.5444   1st Qu.:0.5540   1st Qu.:0.5542   1st Qu.:0.5892
## Median :0.5896   Median :0.6046   Median :0.5978   Median :0.6278
## Mean      :0.5858   Mean      :0.5970   Mean      :0.5992   Mean      :0.6302
## 3rd Qu.:0.6310   3rd Qu.:0.6323   3rd Qu.:0.6458   3rd Qu.:0.6682
## Max.      :0.7207   Max.      :0.7593   Max.      :0.7471   Max.      :0.7556
```

```
apply(TestPrecisionMacroAve,2,"sd")
```

```
## [1] 0.06339133 0.05911484 0.05834886 0.05919884
```

```
RESprecision <- rbind(apply(FitPrecisionMacroAve,2,"mean"), apply(FitPrecisionMacroAve,2,"sd"),
                      apply(TestPrecisionMacroAve,2,"mean"), apply(TestPrecisionMacroAve,2,"sd"))
colnames(RESprecision) = columna
rownames(RESprecision) = renglon
write.csv(RESprecision, file=paste0(archivo,"_precision",".csv"))
```

Recall Macro Average

```
summary(FitRecallMacroAve)
```

```
##           V1           V2           V3           V4
##  Min.    :1  Min.    :1  Min.    :1  Min.    :1
## 1st Qu.:1  1st Qu.:1  1st Qu.:1  1st Qu.:1
## Median :1  Median :1  Median :1  Median :1
## Mean    :1  Mean    :1  Mean    :1  Mean    :1
## 3rd Qu.:1  3rd Qu.:1  3rd Qu.:1  3rd Qu.:1
## Max.    :1  Max.    :1  Max.    :1  Max.    :1
```

```
apply(FitRecallMacroAve,2,"sd")
```

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

```
summary(TestRecallMacroAve)
```

```
##           V1           V2           V3           V4
##  Min.    :0.4386  Min.    :0.4211  Min.    :0.4561  Min.    :0.4386
## 1st Qu.:0.5395  1st Qu.:0.5570  1st Qu.:0.5570  1st Qu.:0.5789
## Median :0.5789  Median :0.5965  Median :0.5965  Median :0.6316
## Mean    :0.5800  Mean    :0.5882  Mean    :0.5933  Mean    :0.6265
## 3rd Qu.:0.6316  3rd Qu.:0.6316  3rd Qu.:0.6316  3rd Qu.:0.6667
## Max.    :0.7193  Max.    :0.7193  Max.    :0.7368  Max.    :0.7544
```

```
apply(TestRecallMacroAve,2,"sd")
```

```
## [1] 0.06366290 0.05465739 0.05748111 0.05769247
```

```
RESrecall <- rbind(apply(FitRecallMacroAve,2,"mean"), apply(FitRecallMacroAve,2,"sd"),
                  apply(TestRecallMacroAve,2,"mean"), apply(TestRecallMacroAve,2,"sd"))
colnames(RESrecall) = columna
rownames(RESrecall) = renglon
write.csv(RESrecall, file=paste0(archivo,"_recall",".csv"))
```

F1-Score Macro Average

```
summary(FitF1ScoreMacroAve)
```

```
##           V1           V2           V3           V4
## Min.      :1   Min.      :1   Min.      :1   Min.      :1
## 1st Qu.:1   1st Qu.:1   1st Qu.:1   1st Qu.:1
## Median :1   Median :1   Median :1   Median :1
## Mean      :1   Mean      :1   Mean      :1   Mean      :1
## 3rd Qu.:1   3rd Qu.:1   3rd Qu.:1   3rd Qu.:1
## Max.      :1   Max.      :1   Max.      :1   Max.      :1
```

```
apply(FitF1ScoreMacroAve,2,"sd")
```

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

```
summary(TestF1ScoreMacroAve)
```

```
##           V1           V2           V3           V4
## Min.      :0.4383   Min.      :0.4272   Min.      :0.4568   Min.      :0.4383
## 1st Qu.:0.5357   1st Qu.:0.5480   1st Qu.:0.5496   1st Qu.:0.5797
## Median :0.5815   Median :0.5915   Median :0.5918   Median :0.6231
## Mean      :0.5784   Mean      :0.5866   Mean      :0.5911   Mean      :0.6220
## 3rd Qu.:0.6273   3rd Qu.:0.6282   3rd Qu.:0.6305   3rd Qu.:0.6639
## Max.      :0.7187   Max.      :0.7207   Max.      :0.7407   Max.      :0.7507
```

```
apply(TestF1ScoreMacroAve,2,"sd")
```

```
## [1] 0.06308804 0.05589570 0.05772013 0.05970084
```

```
RESf1score <- rbind(apply(FitF1ScoreMacroAve,2,"mean"), apply(FitF1ScoreMacroAve,2,"sd"),
                    apply(TestF1ScoreMacroAve,2,"mean"), apply(TestF1ScoreMacroAve,2,"sd"))
colnames(RESf1score) = columna
rownames(RESf1score) = renglon
write.csv(RESf1score, file=paste0(archivo,"_f1score",".csv"))
```