

# The Principle of R Package GSClassifier

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2022-09-14



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# Chapter 1

## The Principle of GSClassifier

### 1.1 Introduction

[GSClassifier](#) is an R package for modeling and identification of gene expression profiles (GEPs) subtypes. The detail of usage had been demonstrated in [Github WiKi](#). Here, we propose to introduce the principle of GSClassifier, including flowchart, **top scoring pairs (TSP)** algorithm, and batch effect control.

### 1.2 Flowchart

The flowchart of **GSClassifier** is showed in Figure [1.1](#).

### 1.3 Data Processing

For each dataset, the RNA expression matrix would be normalized (we called **Raw Matrix** in the flowchart) internally so that the expression data of the samples in the dataset were comparable.

Next, the subtypes of the samples in each dataset would be called based on cluster analysis. Specially, we figured out PAD subtypes, which belong to **Subtype Vector** in the flowchart, via hierarchical clustering analysis.

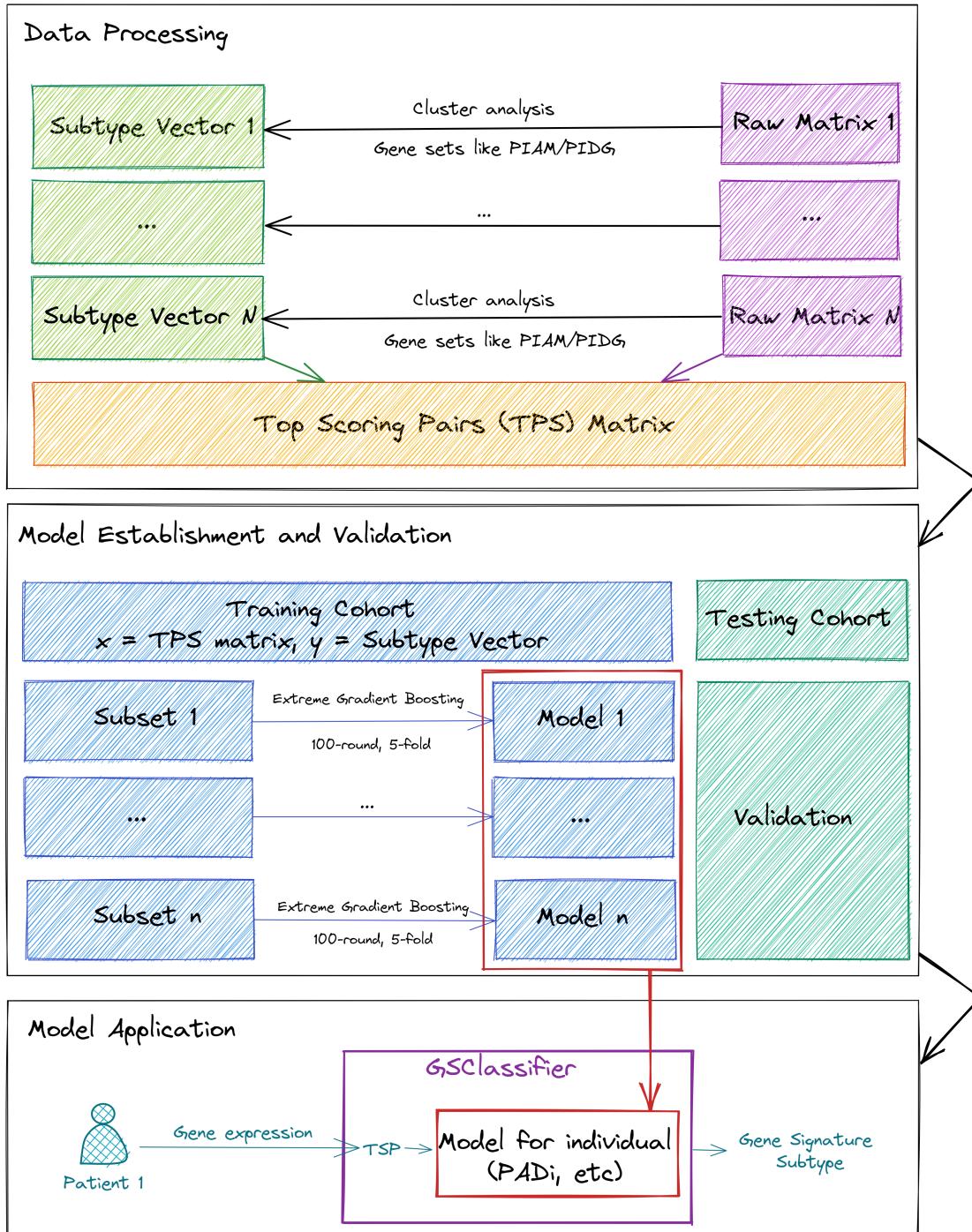


Figure 1.1: The flow chart of GSClassifier

## 1.4 Top scoring pairs (TSP) matrix

With **subtype vectors** and **Raw Matrix**, the TSP matrix for a specified subtypes could be calculated via function `GSClassifier::trainDataProc`:

```
trainDataProc(
  Xmat, Yvec,
  geneSet,
  subtype = 1,
  # 0.2 was Used in PAD project
  ptail = 0.2,
  # c(0, 0.25, 0.5, 0.75, 1.0) was Used in PAD project
  breakVec = c(0, 0.25, 0.5, 0.75, 1.0)
)
```

As show in Figure 1.2, The TSP matrix consists of 3 parts: **binned expression**, **pair difference**, and **set difference**.

Next, we would use a simulated dataset to introduce **how TSP matrix calculated in `GSClassifier`**.

### 1.4.1 Simulated Dataset

First, load needed packages:

```
# Install "devtools" package
if (!requireNamespace("devtools", quietly = TRUE))
  install.packages("devtools")
```

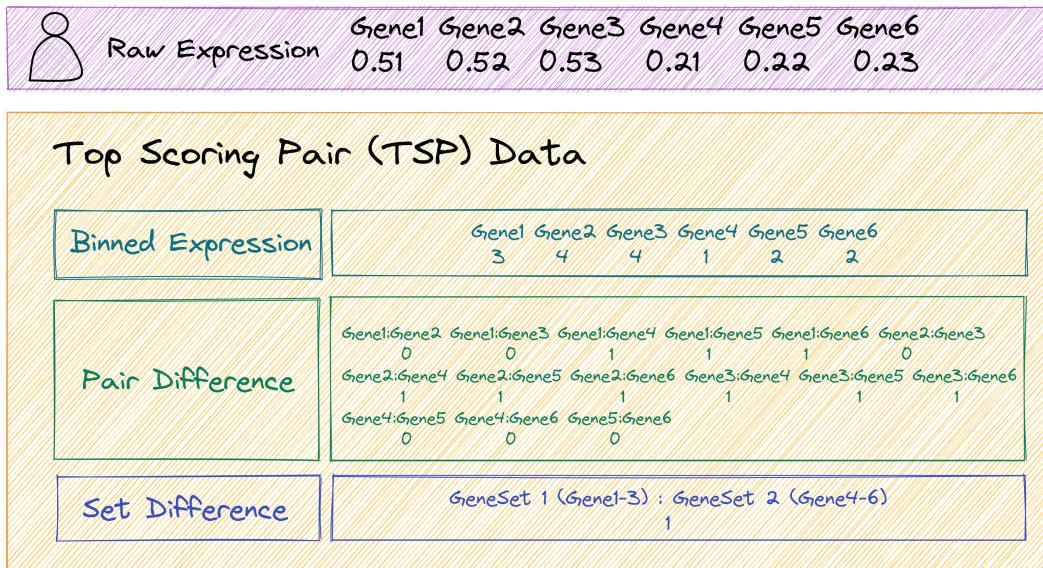


Figure 1.2: The components of TSP (2 gene sets)

```

# Install dependencies
if (!requireNamespace("luckyBase", quietly = TRUE))
  devtools::install_github("huangwb8/luckyBase")

# Install the "GSClassifier" package
if (!requireNamespace("GSClassifier", quietly = TRUE))
  devtools::install_github("huangwb8/GSClassifier")

# Install the "pacman" package
if (!requireNamespace("pacman", quietly = TRUE)){
  install.packages("pacman")
  library(pacman)
} else {
  library(pacman)
}

# Load needed packages

```

```
packages_needed <- c(
  "readxl",
  "ComplexHeatmap",
  "GSClassifier",
  "rpart",
  "tidyverse")
for(i in packages_needed){p_load(char=i)}
```

We simulated a dataset:

```
# Geneset
geneSet <- list(
  Set1 = paste('Gene',1:3,sep = ''),
  Set2 = paste('Gene',4:6,sep = '')
)

# RNA expression
x <- read_xlsx('./data/simulated-data.xlsx', sheet = 'RNA')
expr0 <- as.matrix(x[,-1])
rownames(expr0) <- as.character(as.matrix(x[,1])); rm(x)

# Parameters
breakVec = c(0, 0.25, 0.5, 0.75, 1.0)
subtype_vector = c(1,1,1,2,2,2)
Ybin = ifelse(subtype_vector == 1, yes = 1, no=0)

# Report
cat(c('\n', 'Gene sets:', '\n'))
print(geneSet)
cat('RNA expression:', '\n')
print(expr0)
```

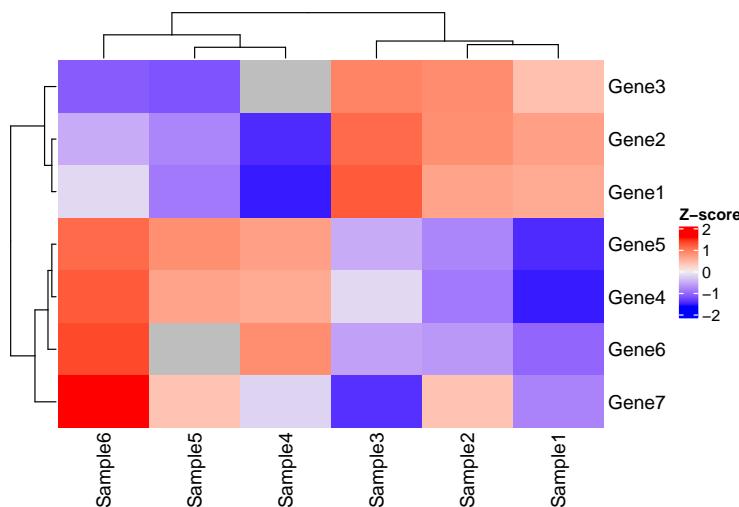
```

#
# Gene sets:
# $Set1
# [1] "Gene1" "Gene2" "Gene3"
#
# $Set2
# [1] "Gene4" "Gene5" "Gene6"
#
# RNA expression:
#           Sample1 Sample2 Sample3 Sample4 Sample5 Sample6
# Gene1      0.51   0.52   0.60   0.21   0.30   0.40
# Gene2      0.52   0.54   0.58   0.22   0.31   0.35
# Gene3      0.53   0.60   0.61    NA   0.29   0.30
# Gene4      0.21   0.30   0.40   0.51   0.52   0.60
# Gene5      0.22   0.31   0.35   0.52   0.54   0.58
# Gene6      0.23   0.29   0.30   0.53    NA   0.61
# Gene7      0.10   0.12   0.09   0.11   0.12   0.14

```

Look at the matrix via heatmap:

```
Heatmap(t(scale(t(expr0))), name = "Z-score")
```



This is an interesting dataset with features as following:

- **Distinguished gene sets:** The expression profile between **Gene 1-3** and **Gene 4-6** is obviously different across samples. Thus, these gene sets might represent different biology meaning.
- **Stable gene:** The expression level and rank of **Gene 7** seemed to be similar across samples. Thus, **Gene 7** might not be a robust marker for subtype modeling. Thus, it could help us to understand how filtering of **GSClassifier** works.
- **Expression heterogeneity & rank homogeneity:** Take **Sample1** and **Sample3** as examples. The expression of **Gene 1-6** in **Sample3** seemed to be higher than those of **Sample1**. However, the expression of **Gene 1-3** is higher than **Gene 4-6** in both **Sample1** and **Sample3**, indicating similar bioprocess in these samples exists so that they should be classified as the same subtype.

### 1.4.2 Missing values

Here, we fill missing value with Recursive Partitioning and Regression Trees (RPART) algorithm:

```
# RPART
expr <- GSClassifier:::na_fill(expr0, method="anova", na.action = na.rpart)

# Report
cat('RNA expression:', '\n')
print(expr0)
cat('\n')
cat('RNA expression without NA value:', '\n')
print(expr)

# RNA expression:
#      Sample1 Sample2 Sample3 Sample4 Sample5 Sample6
# Gene1    0.51    0.52    0.60    0.21    0.30    0.40
```

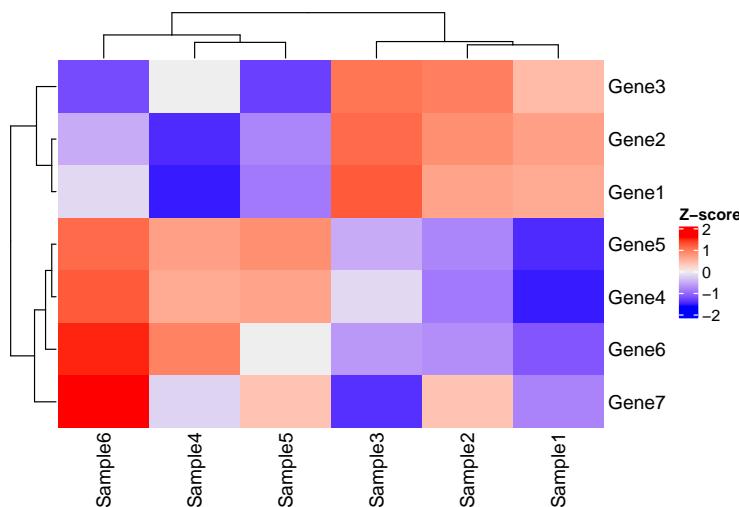
```

# Gene2    0.52    0.54    0.58    0.22    0.31    0.35
# Gene3    0.53    0.60    0.61    NA      0.29    0.30
# Gene4    0.21    0.30    0.40    0.51    0.52    0.60
# Gene5    0.22    0.31    0.35    0.52    0.54    0.58
# Gene6    0.23    0.29    0.30    0.53    NA      0.61
# Gene7    0.10    0.12    0.09    0.11    0.12    0.14
#
# RNA expression without NA value:
#           Sample1 Sample2 Sample3 Sample4 Sample5 Sample6
# Gene1    0.51    0.52    0.60    0.210   0.300   0.40
# Gene2    0.52    0.54    0.58    0.220   0.310   0.35
# Gene3    0.53    0.60    0.61    0.466   0.290   0.30
# Gene4    0.21    0.30    0.40    0.510   0.520   0.60
# Gene5    0.22    0.31    0.35    0.520   0.540   0.58
# Gene6    0.23    0.29    0.30    0.530   0.392   0.61
# Gene7    0.10    0.12    0.09    0.110   0.120   0.14

```

Look at the new matrix via heatmap, where the clustering result is not obviously disturbed by **NA** filling:

```
Heatmap(t(scale(t(expr))), name = "Z-score")
```



Although RPART algorithm is proved to be powerful dealing with NA value, we should try to use markers with less NA as possible. During PAD subtype establishment, only genes occurring in over 80% of datasets were retained so as to minimize the impact from missing value.

### 1.4.3 Binned expression

First, we binned genes with different quantile intervals so that the distribution of rank information could be more consistent across samples.

Take data of **Sample4** as an example:

```
# Data of Sample4

x <- expr[,4]

# Create quantiles
brks <- quantile(as.numeric(x),
                  probs=breakVec,
                  na.rm = T)

# Get interval orders
xbin <- .bincode(x = x,
                  breaks = brks,
                  include.lowest = T)

xbin <- as.numeric(xbin)
names(xbin) <- names(x)

# Report
cat('Quantiles:', '\n'); print(brks)
cat('\n')
```

```

cat('Raw expression:', '\n');print(x)
cat('\n')
cat('Binned expression:', '\n'); print(xbin)

# Quantiles:
#    0%   25%   50%   75%  100%
# 0.110 0.215 0.466 0.515 0.530
#
# Raw expression:
# Gene1 Gene2 Gene3 Gene4 Gene5 Gene6 Gene7
# 0.210 0.220 0.466 0.510 0.520 0.530 0.110
#
# Binned expression:
# Gene1 Gene2 Gene3 Gene4 Gene5 Gene6 Gene7
#     1     2     2     3     4     4     1

```

For example, **0.110** is the minimum of the raw expression vector, so its binned expression is **1**. Similarly, the binned expression of maximum **0.530** is **4**.

Generally, we calculate binned expression via function **breakBin** of **GSClassifier**:

```

expr_binned <- apply(
  expr, 2,
  GSClassifier:::breakBin,
  breakVec)

rownames(expr_binned) <- rownames(expr)

print(expr_binned)

#      Sample1 Sample2 Sample3 Sample4 Sample5 Sample6
# Gene1      3      3      4      1      2      2
# Gene2      4      4      3      2      2      2
# Gene3      4      4      4      2      1      1
# Gene4      1      2      2      3      4      4

```

# Gene5	2	2	2	4	4	3
# Gene6	2	1	1	4	3	4
# Gene7	1	1	1	1	1	1

In this simulated dataset, **Gene7** is a gene whose expression is always the lowest across all samples. In other words, the rank of **Gene7** is stable or invariable across samples so that it's not robust for identification of differentail subtypes.

Except binned expression, we also calculated pair difference later. Due to the number of gene pair is  $C_2$ , the removement of genes like **Gene7** before modeling could really reduce the complexity and save computing resources. In all, genes with low rank difference should be dropped out in some extent in **GSClassifier**.

First, We use **base::rank** to return the sample ranks of the values in a vector:

```
expr_binned_rank <- apply(
  expr_binned, 2,
  function(x)rank(x, na.last = TRUE)
)
print(expr_binned_rank)

#           Sample1 Sample2 Sample3 Sample4 Sample5 Sample6
# Gene1      5.0    5.0    6.5    1.5    3.5    3.5
# Gene2      6.5    6.5    5.0    3.5    3.5    3.5
# Gene3      6.5    6.5    6.5    3.5    1.5    1.5
# Gene4      1.5    3.5    3.5    5.0    6.5    6.5
# Gene5      3.5    3.5    3.5    6.5    6.5    5.0
# Gene6      3.5    1.5    1.5    6.5    5.0    6.5
# Gene7      1.5    1.5    1.5    1.5    1.5    1.5
```

Then, get rank differences of each gene based on specified subtype distribution (**Ybin**):

```
testRes <- sapply(
  1:nrow(expr_binned_rank),
```

```

function(gi){
  GSClassifier:::testFun(
    as.numeric(expr_binned_rank[gi,]),
    Ybin)
}

names(testRes) <- rownames(expr_binned_rank)
print(testRes)
#      Gene1      Gene2      Gene3      Gene4      Gene5      Gene6      Gene7
# -2.666667 -2.500000 -4.333333  3.166667  2.500000  3.833333  0.000000

```

**Gene7** is the one with the lowest absolute value (0) of rank difference.

In **GSClassifier**, we use **ptail** to select differential genes based on rank differences. Less **ptail** is, less gene kept. Here, we just set **ptail=0.4**:

```

# ptail is a number ranging (0,0.5].
ptail = 0.4

# Index of target genes with big rank differences
idx <- which((testRes < quantile(testRes, ptail, na.rm = T)) |
               (testRes > quantile(testRes, 1.0-ptail, na.rm = T)))

# Target genes
gene_bigRank <- names(testRes)[idx]

# Report
cat('Index of target genes: ', '\n'); print(idx); cat('\n')
cat('Target genes:', '\n'); print(gene_bigRank); cat('\n')
# Index of target genes:
# Gene1 Gene2 Gene3 Gene4 Gene5 Gene6

```

```
#      1      2      3      4      5      6
#
# Target genes:
# [1] "Gene1" "Gene2" "Gene3" "Gene4" "Gene5" "Gene6"
```

Hence, **Gene7** was filtered and excluded in the following analysis. In practice, both **ptail** and **breakVec** are hyperparameters in GSClassifier modeling.

#### 1.4.4 Pair difference

In GSClassifier, we use a ensemble function **featureSelection** to select data for pair difference scoring.

```
expr_feat <- featureSelection(expr, Ybin,
                                testRes = testRes,
                                ptail = 0.4)

expr_sub <- expr_feat$Xsub
gene_bigRank <- expr_feat$Genes

# Report
cat('Raw xpression:', '\n')
print(expr[gene_bigRank,])
cat('\n')
cat('Raw xpression without NA:', '\n')
print(expr_sub)
cat('\n')
cat('Genes with large rank diff:', '\n')
print(gene_bigRank)
# Raw xpression:
#      Sample1 Sample2 Sample3 Sample4 Sample5 Sample6
```

```

# Gene1 0.51 0.52 0.60 0.210 0.300 0.40
# Gene2 0.52 0.54 0.58 0.220 0.310 0.35
# Gene3 0.53 0.60 0.61 0.466 0.290 0.30
# Gene4 0.21 0.30 0.40 0.510 0.520 0.60
# Gene5 0.22 0.31 0.35 0.520 0.540 0.58
# Gene6 0.23 0.29 0.30 0.530 0.392 0.61
#
# Raw expression without NA:
#       Sample1 Sample2 Sample3 Sample4 Sample5 Sample6
# Gene1 0.51 0.52 0.60 0.210 0.300 0.40
# Gene2 0.52 0.54 0.58 0.220 0.310 0.35
# Gene3 0.53 0.60 0.61 0.466 0.290 0.30
# Gene4 0.21 0.30 0.40 0.510 0.520 0.60
# Gene5 0.22 0.31 0.35 0.520 0.540 0.58
# Gene6 0.23 0.29 0.30 0.530 0.392 0.61
#
# Genes with large rank diff:
# [1] "Gene1" "Gene2" "Gene3" "Gene4" "Gene5" "Gene6"

```

In GSClassifier, we use function **makeGenePairs** to calculate s

```

gene_bigRank_pairs <- GSClassifier:::makeGenePairs(
  gene_bigRank,
  expr[gene_bigRank,])
print(gene_bigRank_pairs)
#       Sample1 Sample2 Sample3 Sample4 Sample5 Sample6
# Gene1:Gene2 0 0 1 0 0 1
# Gene1:Gene3 0 0 0 0 1 1
# Gene1:Gene4 1 1 1 0 0 0
# Gene1:Gene5 1 1 1 0 0 0
# Gene1:Gene6 1 1 1 0 0 0

```

# Gene2:Gene3	0	0	0	0	1	1
# Gene2:Gene4	1	1	1	0	0	0
# Gene2:Gene5	1	1	1	0	0	0
# Gene2:Gene6	1	1	1	0	0	0
# Gene3:Gene4	1	1	1	0	0	0
# Gene3:Gene5	1	1	1	0	0	0
# Gene3:Gene6	1	1	1	0	0	0
# Gene4:Gene5	0	0	1	0	0	1
# Gene4:Gene6	0	1	1	0	1	0
# Gene5:Gene6	0	1	1	0	1	0

Take **Gene1:Gene4** of **Sample1** as an example.  $Expression_{Gene1} - Expression_{Gene4} = 0.51 - 0.21 = 0.3 > 0$ , so the pair score is 1. If the difference is less than or equal to 0, the pair score is 0.

#### 1.4.5 Set difference

In GSClassifier, we use function **makeSetData** to calculate gene set difference score:

```
geneset_interaction <- GSClassifier:::makeSetData(expr,geneSet)
print(geneset_interaction)

#      Sample1 Sample2 Sample3 Sample4 Sample5 Sample6
# s1s2      1      1      1      0      0      0
```