

Antonin Rosa

Hendrik Wellmann

Practical 3 Statistical Genetics

Linkage disequilibrium

```
library(haplo.stats)
```

Question 1

```
## Loading required package: arsenal
library(genetics)

## Loading required package: combinat
##
## Attaching package: 'combinat'
## The following object is masked from 'package:utils':
##       combn

## Loading required package: gdata
##
## Attaching package: 'gdata'
## The following object is masked from 'package:stats':
##       nobs
##       object.size
## The following object is masked from 'package:utils':
##       startsWith
## Loading required package: gtools
## Loading required package: MASS
## Loading required package: mvtnorm
##
## NOTE: THIS PACKAGE IS NOW OBSOLETE.
##
##      The R-Genetics project has developed an set of enhanced genetics
##      packages to replace 'genetics'. Please visit the project homepage
##      at http://rgenetics.org for information.
##
## Attaching package: 'genetics'
```

```

## The following object is masked from 'package:haplo.stats':
##
##      locus

## The following objects are masked from 'package:base':
##
##      %in%, as.factor, order
library(HardyWeinberg)

## Loading required package: mice

##
## Attaching package: 'mice'

## The following object is masked from 'package:stats':
##
##      filter

## The following objects are masked from 'package:base':
##
##      cbind, rbind

## Loading required package: Rsolnp

## Loading required package: nnet

data <- read.table("FOXP2/FOXP2.dat", header = TRUE, sep = " ")
num_individuals <- nrow(data) -1
num_snps <- ncol(data) - 1

cat("Number of individuals:", num_individuals, "\n")

## Number of individuals: 103
cat("Number of SNPs:", num_snps, "\n")

## Number of SNPs: 543

missing_percentage <- mean(is.na(data)) * 100
cat("Percentage of missing data:", missing_percentage, "%\n")

## Percentage of missing data: 0 %

g1 <- genotype(data$rs34684677)
g2 <- genotype(data$rs2894715)
LD(g1,g2)

```

Question 2

```

##
## Pairwise LD
## -----
##          D       D'       Corr
## Estimates: -0.05493703 0.9986536 -0.3144048
##
##          X^2      P-value    N
## LD Test: 20.56088 5.77645e-06 104

```

The SNPs rs34684677 and rs2894715 show a strong genetic linkage, meaning that variations in one SNP are highly likely to be associated with variations in the other. The high D' value (0.9986536) indicates a strong linkage. The moderate negative correlation (Corr = -0.3144048) suggests that variations in allele frequencies tend to occur in opposite directions. In summary, there's a significant and non-random association between alleles of rs34684677 and rs2894715, with a tendency for opposite variations.

Question 3 Low LD ($D = -0.05493703$) suggests weak association between SNPs rs34684677 and rs2894715. Haplotypes are likely formed independently. Estimate haplotype frequencies from genotype frequencies. The most common haplotype has the highest estimated frequency. Provide genotype frequencies for detailed calculation

```
snp1 <- data$rs34684677
snp2 <- data$rs2894715
genotype_matrix <- cbind(substr(snp1, 1, 1), substr(snp1, 3, 3),
                         substr(snp2, 1, 1), substr(snp2, 3, 3))

snpnames <- c("snp1", "snp2")
haplo_freq <- haplo.em(genotype_matrix, locus.label=snpnames <- c("snp1", "snp2"))
print(haplo_freq)

## =====
##                               Haplotypes
## =====
##   snp1 snp2 hap.freq
## 1   G   G  0.33654
## 2   G   T  0.50000
## 3   T   G  0.00000
## 4   T   T  0.16346
## =====
##                               Details
## =====
## lnlike = -164.8458
## lr stat for no LD = 18.69923 , df = 0 , p-val = NA
```

The answer is SNP1=G and SNP2=T.

```
bim_file <- "FOXP2/FOXP2.bim"
bim_data <- read.table(bim_file, header = FALSE, stringsAsFactors = FALSE)

genotype_matrix <- data[,-1]
for (col in colnames(genotype_matrix)) {
  genotype_matrix[[col]] <- genotype(genotype_matrix[[col]])
}
calculate_MAF <- function(genotype_counts) {
  allele1 <- 2 * genotype_counts[[1]] + genotype_counts[[2]]
  allele2 <- 2 * genotype_counts[[3]] + genotype_counts[[2]]
  return (min(allele1, allele2) / (allele2 + allele1))
}

filter_index_MAF <- c()
res <- 0
for (i in 1:ncol(genotype_matrix)) {
  alleles <- c(paste(bim_data$V5[[i]], "/", bim_data$V6[[i]], sep = ""))
  count_gentotype <- MakeCounts(genotype_matrix[[i]], alleles = alleles, sep="/")
```

```

MAF <- calculate_MAF(count_gentotype)
if (MAF < 0.35) {
  filter_index_MAF <- c(filter_index_MAF, i)
}
p_value <- HWE.chisq(genotype_matrix[[i]])
p_value <- p_value$p.value
if (p_value < 0.05) {
  res <- res + 1
}
}
print(res)

```

Question 4

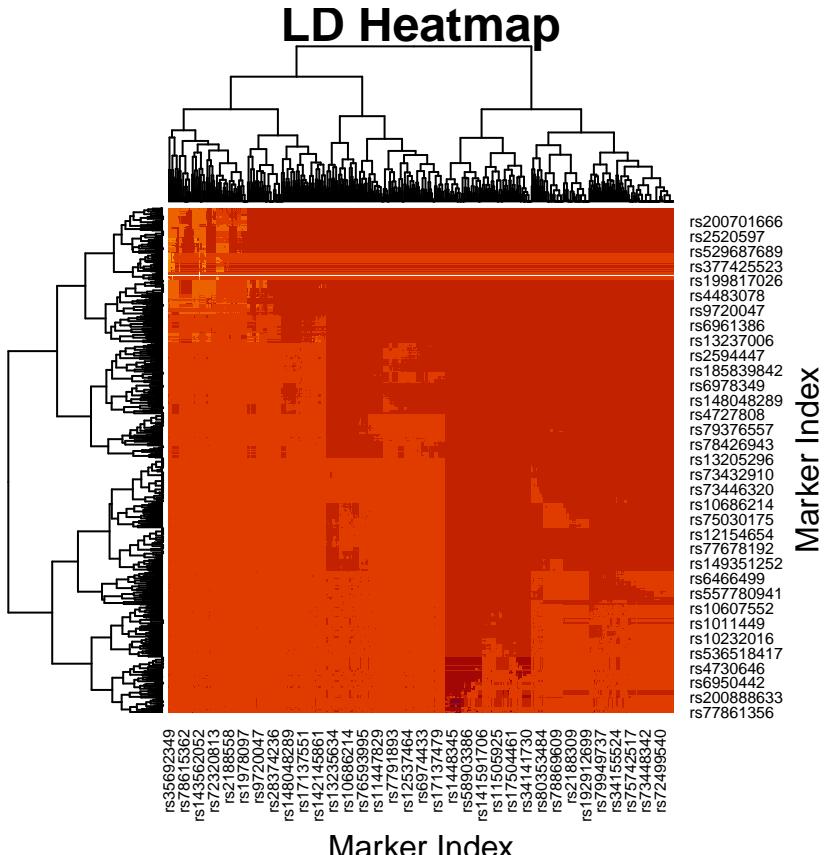
```
## [1] 18
```

We can reject 18 variants.

```

ld_matrix <- LD(genotype_matrix)
r2_matrix <- ld_matrix$`R^2`
r2_matrix[is.na(r2_matrix)] <- 1
heatmap(r2_matrix, main = "LD Heatmap", xlab = "Marker Index", ylab = "Marker Index")

```



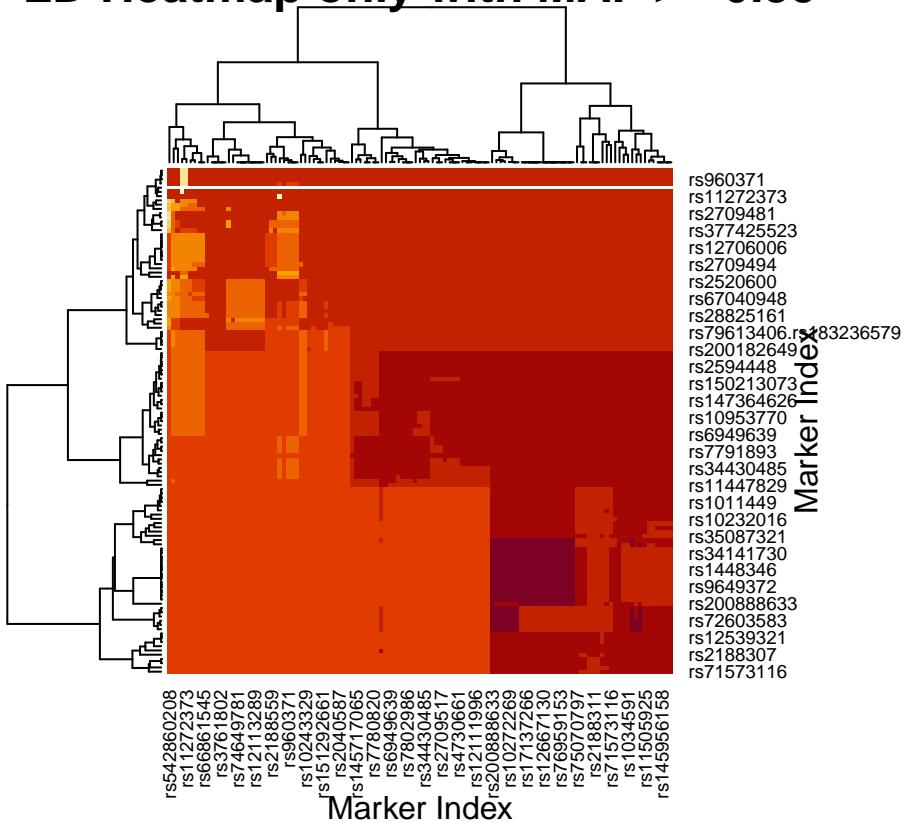
Question 5

```

r2_matrix <- r2_matrix[-filter_index_MAF, -filter_index_MAF]
heatmap(r2_matrix, main = "LD Heatmap only with MAF >= 0.35", xlab = "Marker Index", ylab = "Marker Index")

```

LD Heatmap only with MAF >= 0.35



Question 6

Question 7

Haplotype estimation

```
data <- read.table("APOE/APOE.dat", header = TRUE, sep = " ")
num_individuals <- nrow(data) - 1
num_snps <- ncol(data) - 1
cat("Number of individuals:", num_individuals, "\n")
```

Question 1

```
## Number of individuals: 106
cat("Number of SNPs:", num_snps, "\n")

## Number of SNPs: 162
missing_percentage <- mean(is.na(data)) * 100
cat("Percentage of missing data:", missing_percentage, "%\n")

## Percentage of missing data: 0 %
```

Question 2 We can theoretically find 2^{544} .

```

n_line <- nrow(data)
n_col <- 2 * ncol(data)
Geno <- matrix(0, nrow = n_line, ncol = n_col)

for (i in 1:ncol(data)) {
  col_start <- (i - 1) * 2 + 1
  Geno[, col_start] <- substr(data[, i], 1, 1)
  Geno[, col_start + 1] <- substr(data[, i], 3, 3)
}
options(max.print = 100000)

haplo_freq <- haplo.em(Geno)
print(haplo_freq)

```

Question 3

```

## =====
##                               Haplotypes
## =====
##   loc-1 loc-2 loc-3 loc-4 loc-5 loc-6 loc-7 loc-8 loc-9 loc-10 loc-11 loc-12
## 1    2      C      C      C      G      C      A      C      G      G      C      T
## 2    2      C      C      C      G      C      A      C      G      G      C      T
## 3    2      C      C      C      G      C      A      C      G      G      C      T
## 4    2      C      C      C      G      C      A      C      G      G      C      T
## 5    2      C      C      C      G      C      A      C      G      G      C      T
## 6    2      C      C      C      G      C      A      C      G      G      C      T
## 7    2      C      C      C      G      C      G      C      A      C      C      T
## 8    2      C      C      C      G      C      G      C      G      C      C      T
## 9    2      C      C      C      G      C      G      C      G      C      C      T
## 10   2      C      C      C      G      C      G      C      G      C      C      T
## 11   2      C      C      C      G      C      G      C      G      C      C      T
## 12   2      C      C      C      G      C      G      C      G      C      C      T
## 13   2      C      C      C      G      C      G      C      G      C      C      T
## 14   2      C      C      C      G      C      G      C      G      C      C      T
## 15   2      C      C      C      G      C      G      C      G      C      C      T
## 16   2      C      C      C      G      C      G      C      G      C      C      T
## 17   2      C      C      C      G      C      G      C      G      C      C      T
## 18   2      C      C      C      G      C      G      C      G      G      C      T
## 19   2      C      C      C      G      C      G      C      G      G      C      T
## 20   2      C      C      C      G      C      G      C      G      G      C      T
## 21   2      C      C      C      G      C      G      C      G      G      C      T
## 22   2      C      C      C      G      C      G      C      G      G      C      T
## 23   2      C      C      C      G      C      G      C      G      G      C      T
## 24   2      C      C      C      G      C      G      C      G      G      C      T
## 25   2      C      C      C      G      C      G      C      G      G      C      T
## 26   2      C      C      C      G      C      G      C      G      G      C      T
## 27   2      C      C      C      G      C      G      C      G      G      C      T
## 28   2      C      C      C      G      C      G      C      G      G      C      T
## 29   2      C      C      C      G      C      G      C      G      G      C      T
## 30   2      C      C      C      G      C      G      C      G      G      C      T
## 31   2      C      C      C      G      C      G      C      G      G      C      T
## 32   2      C      C      C      G      C      G      C      G      G      C      T
## 33   2      C      C      C      G      C      G      C      G      G      C      T

```

```

## 34   2   C   C   C   G   C   G   C   G   G   C   C   T
## 35   2   G   C   C   G   C   G   C   G   G   C   C   T
## 36   N   C   C   C   G   C   G   C   G   G   C   C   T
## 37   N   C   C   C   G   C   G   C   G   G   C   C   T
## 38   N   C   C   C   G   C   G   C   G   G   C   C   T
## 39   N   C   C   C   G   C   G   C   G   G   C   C   T
## 40   N   C   C   C   G   C   G   C   G   G   C   C   T
## 41   N   C   C   C   G   C   G   C   G   G   C   C   T

##    loc-13 loc-14 loc-15 loc-16 loc-17 loc-18 loc-19 loc-20 loc-21 loc-22 loc-23
## 1     G     C     C     C     G     G     G     C     T     C     A
## 2     G     C     C     C     G     G     G     C     T     C     A
## 3     G     C     C     C     G     G     G     C     T     C     A
## 4     G     C     C     C     G     G     G     C     T     C     A
## 5     G     C     C     C     G     G     G     C     T     C     A
## 6     G     C     C     C     G     G     G     C     T     C     A
## 7     G     C     C     C     G     G     G     C     T     C     A
## 8     G     A     C     C     G     G     G     C     T     C     A
## 9     G     C     C     C     A     G     G     C     T     C     A
## 10    G     C     C     C     A     G     G     C     T     C     A
## 11    G     C     C     C     G     G     A     C     T     C     A
## 12    G     C     C     C     G     G     A     C     T     C     A
## 13    G     C     C     C     G     G     A     C     T     C     A
## 14    G     C     C     C     G     G     A     C     T     C     A
## 15    G     C     C     C     G     G     G     C     T     C     A
## 16    G     C     C     C     G     G     G     C     T     C     A
## 17    G     C     C     C     G     G     G     C     T     C     A
## 18    G     C     C     C     G     G     G     C     T     C     A
## 19    G     C     C     C     G     G     G     C     T     C     A
## 20    G     C     C     C     G     G     G     C     T     C     A
## 21    G     C     C     C     G     G     G     C     T     C     A
## 22    G     C     C     C     G     G     G     C     T     C     A
## 23    G     C     C     C     G     G     G     C     T     C     A
## 24    G     C     C     C     G     G     G     C     T     C     A
## 25    G     C     C     C     G     G     G     C     T     C     A
## 26    G     C     C     C     G     G     G     C     T     C     A
## 27    G     C     C     C     G     G     G     C     T     C     A
## 28    G     C     C     C     G     G     G     C     T     C     A
## 29    G     C     C     C     G     G     G     C     T     C     A
## 30    G     C     C     C     G     G     G     C     T     C     A
## 31    G     C     C     C     G     G     G     C     T     C     A
## 32    G     C     C     C     G     G     G     C     T     C     A
## 33    G     C     C     C     G     G     G     C     T     C     A
## 34    G     C     C     C     G     G     G     C     T     C     A
## 35    G     C     C     C     G     G     G     C     T     C     A
## 36    G     C     C     C     G     G     G     C     T     C     A
## 37    G     C     C     C     A     G     G     C     T     C     A
## 38    G     C     C     C     G     G     G     C     T     C     A
## 39    G     C     C     C     G     G     G     C     T     C     A
## 40    G     C     C     C     G     G     G     C     T     C     A
## 41    G     C     C     C     G     G     G     C     T     C     A

##    loc-24 loc-25 loc-26 loc-27 loc-28 loc-29 loc-30 loc-31 loc-32 loc-33 loc-34
## 1     T     T     C     T     T     A     A     T     C     A     C
## 2     T     T     C     T     T     C     A     T     C     A     C
## 3     T     T     C     T     T     C     A     T     C     A     C

```

```

## 4      T      T      C      T      T      C      A      T      C      A      C
## 5      T      T      C      C      T      C      C      T      C      A      C
## 6      T      T      C      C      T      C      C      T      C      A      C
## 7      T      T      C      C      T      C      C      C      C      A      C
## 8      T      T      C      C      T      C      C      C      C      A      C
## 9      T      T      C      C      T      C      C      C      C      A      C
## 10     T      T      C      C      T      C      C      C      C      A      C
## 11     T      T      C      C      T      C      C      C      C      A      C
## 12     T      T      C      C      T      C      C      C      C      A      C
## 13     T      T      C      C      T      C      C      C      C      A      C
## 14     T      T      C      C      T      C      C      C      C      A      C
## 15     T      T      C      C      T      C      C      C      C      A      C
## 16     T      T      C      C      T      C      C      C      C      A      C
## 17     T      T      C      C      T      C      C      C      C      A      C
## 18     T      T      C      C      T      C      C      C      C      A      C
## 19     T      T      C      C      T      C      C      A      T      C      A
## 20     T      T      C      C      T      C      C      A      T      C      A
## 21     T      T      C      C      T      C      C      A      T      C      A
## 22     T      T      C      C      T      C      C      A      T      C      A
## 23     T      T      C      C      T      C      C      A      T      C      A
## 24     T      T      C      C      T      C      C      A      T      C      A
## 25     T      T      C      C      T      C      C      A      T      C      A
## 26     T      T      C      C      T      C      C      A      T      C      A
## 27     T      T      C      C      T      C      C      A      T      C      A
## 28     T      T      C      C      T      C      C      A      T      C      A
## 29     T      T      C      C      T      C      C      A      T      C      A
## 30     T      T      C      C      T      C      C      A      T      C      A
## 31     T      T      C      C      T      C      C      A      T      C      A
## 32     T      T      C      C      T      C      C      A      T      C      A
## 33     T      T      C      C      T      C      C      A      T      C      A
## 34     T      T      C      C      T      C      C      A      T      C      A
## 35     T      T      C      C      T      C      C      A      T      C      A
## 36     T      T      C      C      T      C      C      A      T      C      A
## 37     T      T      C      C      T      C      C      A      C      C      A
## 38     T      T      C      C      T      C      C      A      T      C      A
## 39     T      T      C      C      T      C      C      A      T      C      A
## 40     T      T      C      C      T      C      C      A      T      C      A
## 41     T      T      C      C      T      C      C      A      T      C      A

## loc-35 loc-36 loc-37 loc-38 loc-39 loc-40 loc-41 loc-42 loc-43 loc-44 loc-45
## 1      C      T      T      A      G      C      C      C      A      C      C
## 2      C      T      C      A      G      C      C      C      A      C      C
## 3      C      T      C      A      G      C      C      C      A      C      C
## 4      C      T      C      A      G      C      C      C      A      C      C
## 5      C      T      C      A      G      C      C      C      A      C      C
## 6      C      T      C      A      G      C      C      C      A      C      C
## 7      C      T      C      G      G      T      C      C      C      C      C
## 8      C      T      C      G      G      T      C      C      C      C      C
## 9      C      T      C      G      G      T      C      C      C      C      C
## 10     C      T      C      G      G      T      C      C      C      C      C
## 11     C      T      C      G      G      T      C      C      C      C      C
## 12     C      T      C      G      G      T      C      C      C      C      C
## 13     C      T      C      G      G      T      C      C      C      C      C
## 14     C      T      C      G      G      T      C      C      C      C      C
## 15     C      T      C      G      G      T      C      C      C      C      C

```

```

## 16   C   T   C   G   G   T   C   C   C   C   C   C   C   C
## 17   C   T   T   G   G   T   C   C   C   C   C   C   C   C
## 18   C   T   C   A   G   C   C   C   C   C   C   C   C   C
## 19   C   T   C   A   G   C   C   C   C   C   C   C   C   C
## 20   C   T   C   A   G   C   C   C   C   C   C   C   C   C
## 21   C   T   C   A   G   C   C   C   C   C   C   C   C   C
## 22   C   T   C   A   G   C   C   C   C   C   C   C   C   C
## 23   C   T   C   A   G   C   C   C   C   C   C   C   C   C
## 24   C   T   C   A   G   C   C   C   C   C   C   C   C   C
## 25   C   T   C   A   G   C   C   C   C   C   C   C   C   C
## 26   C   T   C   A   G   C   C   C   C   C   C   C   C   C
## 27   C   T   C   A   G   C   C   C   C   C   C   C   C   C
## 28   C   T   C   A   G   C   C   C   C   C   C   C   C   C
## 29   C   T   C   A   G   C   C   C   C   C   C   C   C   C
## 30   C   T   C   A   G   C   C   C   C   C   C   C   C   C
## 31   C   T   C   A   G   C   C   C   C   C   C   C   C   C
## 32   C   T   T   A   G   C   C   C   C   C   C   C   C   C
## 33   C   T   T   A   G   C   C   C   C   C   C   C   C   C
## 34   C   T   T   A   G   C   C   C   C   C   C   C   C   C
## 35   C   T   C   A   G   C   C   C   C   C   C   C   C   C
## 36   C   T   C   A   G   C   C   C   C   C   C   C   C   C
## 37   C   T   C   G   G   T   C   C   C   C   C   C   C   C
## 38   C   T   C   A   G   C   C   C   C   C   C   C   C   C
## 39   C   T   C   A   G   C   C   C   C   C   C   C   C   C
## 40   C   T   C   A   G   C   C   C   C   C   C   C   C   C
## 41   C   T   C   A   G   C   C   C   C   C   C   C   C   C

## loc-46 loc-47 loc-48 loc-49 loc-50 loc-51 loc-52 loc-53 loc-54 loc-55 loc-56
## 1     A   C   C   A   G   T   G   T   T   T   G
## 2     A   C   C   A   G   T   G   T   T   T   G
## 3     A   C   C   A   G   T   G   T   T   T   G
## 4     A   C   C   A   G   T   G   T   T   T   G
## 5     A   C   C   A   G   T   G   T   T   T   G
## 6     A   C   C   A   G   T   G   T   T   T   G
## 7     A   T   C   G   A   T   G   G   T   T   G
## 8     A   T   C   A   A   T   G   G   T   T   G
## 9     A   T   C   A   A   T   G   G   T   T   G
## 10    A   T   C   A   A   T   G   G   T   T   G
## 11    C   T   C   A   A   T   G   G   T   T   G
## 12    C   T   C   A   A   T   G   G   T   T   G
## 13    C   T   C   A   A   T   G   G   T   T   G
## 14    C   T   C   A   A   T   G   G   T   T   G
## 15    A   T   C   A   A   T   G   G   T   T   G
## 16    A   T   C   G   A   T   G   G   T   T   G
## 17    A   T   C   G   A   T   G   G   T   T   G
## 18    A   C   C   A   G   T   G   T   T   T   G
## 19    A   C   C   A   G   T   G   T   T   T   G
## 20    A   C   C   A   G   T   G   T   T   T   G
## 21    A   C   C   A   G   T   G   T   T   T   G
## 22    A   C   C   A   G   T   G   T   T   T   G
## 23    A   C   C   A   G   T   G   T   T   T   G
## 24    A   C   C   A   G   T   G   T   T   T   G
## 25    A   C   C   A   G   T   G   T   T   T   G
## 26    A   C   C   A   G   T   G   T   T   T   G
## 27    A   C   C   A   G   T   G   T   T   T   G

```

```

## 28      A      C      C      C      A      G      T      G      T      T      T      T      G
## 29      A      C      C      C      A      G      T      G      T      T      T      T      G
## 30      A      C      C      C      A      G      T      G      T      T      T      T      G
## 31      A      C      C      C      A      G      T      G      T      T      T      T      G
## 32      A      C      C      C      A      G      T      G      T      T      T      T      G
## 33      A      C      C      C      A      G      T      G      T      T      T      T      G
## 34      A      C      C      C      A      G      T      G      T      T      T      T      G
## 35      A      C      C      C      A      G      T      G      T      T      T      T      G
## 36      A      C      C      C      A      G      T      G      T      T      T      T      G
## 37      A      T      C      C      A      A      T      G      G      T      T      T      T      G
## 38      A      C      C      C      A      G      T      G      T      T      T      T      G
## 39      A      C      C      C      A      G      T      G      T      T      T      T      G
## 40      A      C      C      C      A      G      T      G      T      T      T      T      G
## 41      A      C      C      C      A      G      T      G      T      T      T      T      G

##   loc-57 loc-58 loc-59 loc-60 loc-61 loc-62 loc-63 loc-64 loc-65 loc-66 loc-67
## 1      C      C      C      C      T      G      C      A      C      A      G
## 2      C      C      C      C      T      G      C      A      C      A      G
## 3      C      C      C      C      T      G      C      A      C      A      G
## 4      C      C      C      C      T      G      C      A      C      A      G
## 5      C      C      C      C      T      G      C      A      C      A      G
## 6      C      C      C      C      T      G      C      A      C      A      G
## 7      C      C      C      C      T      G      C      A      C      A      G
## 8      C      C      C      C      T      G      C      A      C      A      G
## 9      C      C      C      C      T      G      C      A      C      A      G
## 10     C      C      C      C      T      G      C      A      C      A      G
## 11     C      C      C      C      T      G      C      A      C      A      G
## 12     C      C      C      C      T      G      C      A      C      A      G
## 13     C      C      C      T      C      T      G      C      A      C      A      G
## 14     C      C      C      T      C      T      G      C      A      C      A      G
## 15     C      C      C      C      C      T      G      C      A      C      A      G
## 16     C      C      C      C      C      T      G      C      A      C      A      G
## 17     C      C      C      C      C      T      G      C      A      C      A      G
## 18     C      C      C      C      C      T      G      C      A      C      A      G
## 19     C      C      C      C      C      T      G      C      A      C      A      G
## 20     C      C      C      C      C      T      G      C      A      C      A      G
## 21     C      C      C      C      C      T      G      C      A      C      A      G
## 22     C      C      C      C      C      T      G      C      A      C      A      G
## 23     C      C      C      C      C      T      G      C      A      C      A      G
## 24     C      C      C      C      C      T      G      C      A      C      A      G
## 25     C      C      C      C      C      T      G      C      A      C      A      G
## 26     C      C      C      C      C      T      G      C      A      C      A      G
## 27     C      C      C      C      C      T      G      C      A      C      A      G
## 28     C      C      C      C      C      T      G      C      A      C      A      G
## 29     C      C      C      C      C      T      G      C      A      C      A      G
## 30     C      C      C      C      C      T      G      C      A      C      A      G
## 31     C      C      C      C      C      T      G      C      A      C      A      G
## 32     C      C      C      C      C      T      G      C      A      C      A      G
## 33     C      C      C      C      C      T      G      C      A      C      A      G
## 34     C      C      C      C      C      T      G      C      A      C      A      G
## 35     C      C      C      C      C      T      G      C      A      C      A      G
## 36     C      C      C      C      C      T      G      C      A      C      A      G
## 37     C      C      C      C      C      T      G      C      A      C      A      G
## 38     C      C      C      C      C      T      G      C      A      C      A      G
## 39     C      C      C      C      C      T      G      C      A      C      A      G

```

```

## 40      C      C      C      C      T      G      C      A      C      A      G
## 41      C      C      C      C      T      G      C      A      C      A      G
##    loc-68 loc-69 loc-70 loc-71 loc-72 loc-73 loc-74 loc-75 loc-76 loc-77 loc-78
## 1       G      G      G      C      A      G      C      G      C      C      T
## 2       G      G      G      C      A      G      C      G      C      A      T
## 3       G      G      G      C      A      G      C      G      C      C      T
## 4       G      G      G      C      A      G      C      G      C      C      T
## 5       G      G      G      C      A      G      C      G      C      C      T
## 6       G      G      G      C      A      G      C      G      C      C      T
## 7       G      G      G      C      A      G      C      G      C      C      C
## 8       G      G      G      C      A      G      C      G      C      C      C
## 9       G      G      G      C      A      G      C      G      C      C      C
## 10      G      G      G      C      A      G      C      G      C      C      C
## 11      G      G      G      C      A      G      C      G      C      C      T
## 12      G      G      G      C      A      G      C      G      C      C      T
## 13      G      G      G      C      A      G      C      G      C      C      T
## 14      G      G      G      C      A      G      C      G      C      C      T
## 15      G      G      G      C      A      G      C      G      C      C      T
## 16      G      G      G      C      A      G      C      G      C      C      C
## 17      G      G      G      C      A      G      C      G      C      C      C
## 18      G      G      G      C      A      G      C      G      C      C      C
## 19      G      G      G      C      A      G      C      G      C      C      C
## 20      G      G      G      C      A      G      C      G      C      C      C
## 21      G      G      G      C      A      G      C      G      C      C      C
## 22      G      G      G      C      A      G      C      G      C      C      C
## 23      G      G      G      C      A      G      C      G      C      C      C
## 24      G      G      G      C      A      G      C      G      C      C      C
## 25      G      G      G      C      A      G      C      G      C      C      C
## 26      G      G      G      C      A      G      C      G      C      C      T
## 27      G      G      G      C      A      G      C      G      C      C      T
## 28      G      G      G      C      A      G      C      G      C      C      T
## 29      G      G      G      C      A      G      C      G      C      C      T
## 30      G      G      G      C      A      G      C      G      C      C      T
## 31      G      G      G      C      A      G      C      G      C      C      T
## 32      G      G      G      C      A      G      C      G      C      C      T
## 33      G      G      G      C      A      G      C      G      C      C      T
## 34      G      G      G      C      A      G      C      G      C      C      T
## 35      G      G      G      C      A      G      C      G      C      C      C
## 36      G      G      G      C      A      G      C      G      C      C      T
## 37      G      G      G      C      A      G      C      G      C      C      C
## 38      G      G      G      C      A      G      C      G      C      C      C
## 39      G      G      G      C      A      G      C      G      C      C      T
## 40      G      G      G      C      A      G      C      G      C      C      T
## 41      G      G      G      C      A      G      C      G      C      C      T
##    loc-79 loc-80 loc-81 loc-82 loc-83 loc-84 loc-85 loc-86 loc-87 loc-88 loc-89
## 1       A      T      C      G      G      T      C      A      T      G      A
## 2       A      T      C      G      G      T      C      A      T      G      A
## 3       A      T      C      G      G      T      C      A      T      G      A
## 4       A      T      C      G      G      T      C      A      T      G      A
## 5       A      T      C      G      G      T      C      A      T      G      A
## 6       A      T      C      G      G      T      C      A      T      G      A
## 7       A      T      T      G      G      A      C      A      T      G      A
## 8       A      T      T      G      G      T      C      A      T      G      A
## 9       A      T      T      G      G      T      C      A      T      G      A

```

```

## 10   A   T   T   T   G   G   C   A   T   G   A
## 11   T   T   T   T   G   G   C   A   T   G   A
## 12   T   T   T   T   G   G   C   A   T   G   A
## 13   T   T   T   T   G   G   C   A   T   G   A
## 14   T   T   T   T   G   G   C   A   T   G   A
## 15   A   T   T   T   G   G   C   A   T   G   A
## 16   A   T   T   T   G   G   C   A   T   G   A
## 17   A   T   T   T   G   G   C   A   T   G   A
## 18   A   T   C   G   G   C   A   T   G   G   A
## 19   A   T   C   G   G   C   A   T   G   G   A
## 20   A   T   C   G   G   C   A   T   G   G   A
## 21   A   T   C   G   G   C   A   T   G   G   A
## 22   A   T   C   G   G   C   A   T   G   G   A
## 23   A   T   C   G   G   C   A   T   G   G   A
## 24   A   T   C   G   G   C   A   T   G   G   A
## 25   T   T   C   G   G   C   A   T   G   G   A
## 26   A   T   C   G   G   C   A   T   G   G   A
## 27   A   T   C   G   G   C   A   T   G   G   A
## 28   A   T   C   G   G   C   A   T   G   G   A
## 29   A   T   C   G   G   C   A   T   G   G   A
## 30   A   T   C   G   G   C   A   T   G   G   A
## 31   A   T   C   G   G   C   A   T   G   G   A
## 32   A   T   C   G   G   C   A   T   G   G   A
## 33   A   T   C   G   G   C   A   T   G   G   A
## 34   A   T   C   G   G   C   A   T   G   G   A
## 35   A   T   C   G   G   C   A   T   G   G   A
## 36   A   T   C   G   G   C   A   T   G   G   A
## 37   A   T   T   G   G   C   A   T   G   G   A
## 38   A   T   C   G   G   C   A   T   G   G   A
## 39   A   T   C   G   G   C   A   T   G   G   A
## 40   A   T   C   G   G   C   A   T   G   G   A
## 41   A   T   C   G   G   C   A   T   G   G   A

## loc-90 loc-91 loc-92 loc-93 loc-94 loc-95 loc-96 loc-97 loc-98 loc-99
## 1     C   C   C   G   G   T   G   G   T   A
## 2     C   C   C   G   G   T   G   G   T   A
## 3     C   C   C   G   G   T   A   G   T   A
## 4     C   C   C   G   G   T   G   G   A   A
## 5     C   C   C   G   G   T   G   G   T   A
## 6     C   C   C   G   G   T   G   G   T   A
## 7     C   C   C   G   G   T   G   G   T   A
## 8     C   C   C   G   G   T   G   G   T   A
## 9     C   C   C   G   G   T   G   G   T   A
## 10    C   C   C   G   G   T   G   G   T   A
## 11    C   C   C   G   G   T   G   G   T   A
## 12    C   C   C   G   G   T   G   G   T   A
## 13    C   C   C   G   G   T   G   G   T   A
## 14    C   C   C   G   G   T   G   G   T   A
## 15    C   C   C   G   G   T   G   G   T   A
## 16    C   C   C   G   G   T   G   G   T   A
## 17    C   C   C   G   G   T   G   G   T   A
## 18    C   C   C   G   G   T   A   G   T   A
## 19    C   C   C   G   G   T   G   A   T   A
## 20    C   C   C   G   G   T   G   G   A   A
## 21    C   C   C   G   G   T   G   G   A   A

```

```

## 22      C      C      C      C      G      G      T      G      G      T      A
## 23      C      C      C      C      G      G      T      G      G      T      A
## 24      C      C      C      C      G      G      T      G      G      T      A
## 25      C      C      C      C      G      G      T      G      G      T      A
## 26      C      C      C      C      G      G      T      A      G      T      A
## 27      C      C      C      C      G      G      T      G      G      A      A
## 28      C      C      C      C      G      G      T      G      G      A      A
## 29      C      C      C      C      G      G      T      G      G      T      A
## 30      C      C      C      C      G      G      T      G      G      T      A
## 31      C      C      C      C      G      G      T      G      G      T      A
## 32      C      C      C      C      G      G      T      A      G      T      A
## 33      C      C      C      C      G      G      T      G      G      T      A
## 34      C      C      C      C      G      G      T      G      G      T      A
## 35      C      C      C      C      G      G      T      A      G      A      A
## 36      C      C      C      C      G      G      T      G      G      T      A
## 37      C      C      C      C      G      G      T      G      G      T      A
## 38      C      C      C      C      G      G      T      G      G      T      A
## 39      C      C      C      C      G      G      T      G      G      A      A
## 40      C      C      C      C      G      G      T      G      G      T      A
## 41      C      C      C      G      G      T      G      G      T      A

##   loc-100 loc-101 loc-102 loc-103 loc-104 loc-105 loc-106 loc-107 loc-108
## 1      T      T      G      A      A      A      A      T      T
## 2      T      T      G      A      A      A      A      T      T
## 3      T      T      G      A      A      A      A      T      T
## 4      T      T      G      A      A      A      A      T      T
## 5      T      T      G      A      A      A      A      T      T
## 6      T      T      G      G      A      A      A      A      T      T
## 7      T      T      G      A      A      A      A      A      T      G
## 8      T      T      G      A      A      A      A      A      T      G
## 9      T      T      G      A      A      A      A      A      T      G
## 10     T      T      G      G      A      A      A      A      A      T      G
## 11     T      T      G      A      A      A      A      A      A      T      G
## 12     T      T      G      G      A      A      A      A      A      T      G
## 13     T      T      G      A      A      A      A      A      A      T      G
## 14     T      T      G      A      A      G      A      A      A      T      G
## 15     T      T      G      A      A      A      A      A      A      T      G
## 16     T      T      G      A      A      A      A      A      A      T      G
## 17     T      T      G      A      A      A      A      A      A      T      G
## 18     T      T      G      A      A      A      A      A      A      T      T
## 19     T      T      G      A      A      A      A      A      A      T      T
## 20     T      T      G      A      A      A      A      A      A      T      T
## 21     T      T      G      G      A      A      A      A      A      T      T
## 22     T      T      G      A      A      A      A      A      A      T      T
## 23     T      T      G      A      A      A      A      A      A      T      T
## 24     T      T      G      G      A      A      A      A      A      T      T
## 25     T      T      G      A      A      A      A      A      A      T      T
## 26     T      T      G      A      A      A      A      A      A      T      T
## 27     T      T      G      A      A      A      A      A      A      T      T
## 28     T      T      G      G      A      A      A      A      A      T      T
## 29     T      T      G      A      A      A      A      A      A      T      G
## 30     T      T      G      A      A      A      A      A      A      T      T
## 31     T      T      G      G      A      A      A      A      A      T      T
## 32     T      T      G      A      A      A      A      A      A      T      T
## 33     T      T      G      A      A      A      A      A      A      T      T

```

```

## 34      T      T      G      G      A      A      A      A      T      T
## 35      T      T      G      A      A      A      A      A      T      T
## 36      T      T      G      A      A      A      A      A      T      T
## 37      T      T      G      A      A      A      A      A      T      G
## 38      T      T      G      A      A      A      A      A      T      T
## 39      T      T      G      A      A      A      A      A      T      T
## 40      T      T      G      A      A      A      A      A      T      G
## 41      T      T      G      A      A      A      A      A      T      T
##   loc-109 loc-110 loc-111 loc-112 loc-113 loc-114 loc-115 loc-116 loc-117
## 1       A       G       T       T       A       G       C       G       A
## 2       A       G       T       T       A       G       C       G       A
## 3       A       G       T       T       A       G       C       G       A
## 4       A       G       T       T       A       G       C       G       A
## 5       A       G       T       T       A       G       C       G       A
## 6       A       G       T       T       A       G       C       G       A
## 7       A       G       T       T       G       T       A       G       A
## 8       A       G       T       T       A       T       A       G       A
## 9       A       G       A       T       A       T       A       G       A
## 10      A       G       A       T       A       T       A       G       A
## 11      A       G       T       T       A       T       C       G       A
## 12      A       G       T       T       A       T       C       G       A
## 13      A       G       T       T       A       T       C       G       A
## 14      A       G       T       T       A       T       C       G       A
## 15      A       G       T       T       A       T       A       G       A
## 16      A       G       T       T       T       G       T       A       G
## 17      A       G       T       T       T       G       T       A       G
## 18      A       G       T       T       A       G       C       G       A
## 19      A       G       T       T       A       G       C       G       A
## 20      A       G       T       T       A       G       C       G       A
## 21      A       G       T       T       A       G       C       G       A
## 22      A       G       T       T       A       G       C       G       A
## 23      A       G       T       T       A       G       C       G       A
## 24      A       G       T       T       A       G       C       G       A
## 25      A       G       T       T       A       G       C       G       A
## 26      A       G       T       T       A       G       C       G       A
## 27      A       G       T       T       A       G       C       G       A
## 28      A       G       T       T       A       G       C       G       A
## 29      A       G       T       T       G       T       A       G       A
## 30      A       G       T       T       A       G       C       G       A
## 31      A       G       T       T       A       G       C       G       A
## 32      A       G       T       T       A       G       C       G       A
## 33      A       G       T       T       A       G       C       G       A
## 34      A       G       T       T       A       G       C       G       A
## 35      A       G       T       T       A       G       C       G       A
## 36      A       G       T       T       A       G       C       G       A
## 37      A       G       A       T       A       T       A       G       A
## 38      A       G       T       T       A       G       C       G       A
## 39      A       G       T       T       A       G       C       G       A
## 40      A       G       T       T       G       T       A       G       A
## 41      A       G       T       T       A       G       C       G       A
##   loc-118 loc-119 loc-120 loc-121 loc-122 loc-123 loc-124 loc-125 loc-126
## 1       C       G       G       G       G       G       T       T       C
## 2       C       G       G       G       G       G       T       T       C
## 3       C       G       G       G       G       G       T       T       C

```

```

## 4      C      G      G      G      G      G      G      G      T      T      T      C
## 5      C      G      G      G      G      G      G      G      T      T      T      C
## 6      C      G      G      G      G      G      G      G      T      T      T      C
## 7      C      G      G      G      G      G      G      G      C      C      T      C
## 8      C      G      G      G      G      G      G      G      T      T      T      C
## 9      C      G      G      G      G      G      G      G      C      C      T      C
## 10     C      G      G      G      G      G      G      G      C      C      T      C
## 11     C      G      G      G      G      G      G      G      C      C      T      C
## 12     C      G      G      G      G      G      G      G      C      C      T      C
## 13     C      G      G      G      G      G      G      G      C      C      T      C
## 14     C      G      G      G      G      G      G      G      C      C      T      C
## 15     C      G      G      G      G      G      G      G      C      C      T      C
## 16     C      G      G      G      G      G      G      G      C      C      T      C
## 17     C      G      G      G      G      G      G      G      C      C      T      C
## 18     C      G      G      G      G      G      G      G      T      T      T      C
## 19     C      G      G      G      G      G      G      G      T      T      T      C
## 20     C      G      G      G      G      G      G      G      T      T      T      C
## 21     C      G      G      G      G      G      G      G      T      T      T      C
## 22     C      G      G      G      G      G      G      G      T      T      T      C
## 23     C      G      G      G      G      G      G      G      T      T      T      C
## 24     C      G      G      G      G      G      G      G      T      T      T      C
## 25     C      G      G      G      G      G      G      G      T      T      T      C
## 26     C      G      G      G      G      G      G      G      T      T      T      C
## 27     C      G      G      G      G      G      G      G      T      T      T      C
## 28     C      G      G      G      G      G      G      G      T      T      T      C
## 29     C      G      G      G      G      G      G      G      C      T      T      C
## 30     C      G      G      G      G      G      G      G      T      T      T      C
## 31     C      G      G      G      G      G      G      G      T      T      T      C
## 32     C      G      G      G      G      G      G      G      T      T      T      C
## 33     C      G      G      G      G      G      G      G      T      T      T      C
## 34     C      G      G      G      G      G      G      G      T      T      T      C
## 35     C      G      G      G      G      G      G      G      T      T      T      C
## 36     C      G      G      G      G      G      G      G      T      T      T      C
## 37     C      G      G      G      G      G      G      G      C      T      T      C
## 38     C      G      G      G      G      G      G      G      T      T      T      C
## 39     C      G      G      G      G      G      G      G      T      T      T      C
## 40     C      G      G      G      G      G      G      G      C      T      T      C
## 41     C      G      G      G      G      G      G      G      T      T      T      C

## loc-127 loc-128 loc-129 loc-130 loc-131 loc-132 loc-133 loc-134 loc-135
## 1      T      T      C      C      G      A      A      A      C      A
## 2      T      T      C      C      G      A      A      A      C      A
## 3      T      T      C      C      G      A      A      A      C      A
## 4      T      T      C      C      G      A      A      A      C      A
## 5      T      T      C      C      G      A      A      A      C      A
## 6      T      T      C      C      G      A      A      A      C      A
## 7      T      T      C      C      G      A      A      A      A      A
## 8      T      T      C      C      G      A      A      A      A      A
## 9      T      T      C      C      G      A      A      A      A      A
## 10     T      T      C      C      G      A      A      A      A      A
## 11     T      T      C      C      G      A      A      A      A      A
## 12     T      T      C      C      G      A      A      A      A      A
## 13     T      T      C      C      G      A      A      A      A      A
## 14     T      T      C      C      G      A      A      A      A      A
## 15     T      T      C      C      G      A      A      A      A      A

```

```

## 16      T      T      T      C      C      G      A      A      A      A
## 17      T      T      T      C      C      G      A      A      A      A
## 18      T      T      T      C      C      G      A      A      C      A
## 19      T      T      T      C      C      G      A      A      C      A
## 20      T      T      T      C      C      G      A      A      C      A
## 21      T      T      T      C      C      G      A      A      C      A
## 22      T      T      T      C      C      G      A      A      A      A
## 23      T      T      T      C      C      G      A      A      C      A
## 24      T      T      T      C      C      G      A      A      C      A
## 25      T      T      T      C      C      G      A      A      C      A
## 26      T      T      T      C      C      G      A      A      C      A
## 27      T      T      T      C      C      G      A      A      C      A
## 28      T      T      T      C      C      G      A      A      C      A
## 29      T      T      T      C      C      G      A      A      A      A
## 30      T      T      T      C      C      G      A      A      C      A
## 31      T      T      T      C      C      G      A      A      C      A
## 32      T      T      T      C      C      G      A      A      C      A
## 33      T      T      T      C      C      G      A      A      C      A
## 34      T      T      T      C      C      G      A      A      C      A
## 35      T      T      T      C      C      G      A      A      C      A
## 36      T      T      T      C      C      G      A      A      C      A
## 37      T      T      T      C      C      G      A      A      A      A
## 38      T      T      T      C      C      G      A      A      C      A
## 39      T      T      T      C      C      G      A      A      C      A
## 40      T      T      T      C      C      G      A      A      A      A
## 41      T      T      T      C      C      G      A      A      C      A
## loc-136 loc-137 loc-138 loc-139 loc-140 loc-141 loc-142 loc-143 loc-144
## 1       C      T      T      C      C      C      C      G      T
## 2       C      T      T      C      C      C      C      G      T
## 3       C      T      T      C      C      C      C      G      T
## 4       C      T      T      C      C      C      C      G      T
## 5       C      T      T      C      C      C      C      G      T
## 6       C      T      T      C      C      C      C      G      T
## 7       C      T      T      C      C      C      C      G      T
## 8       C      T      T      C      C      C      C      G      T
## 9       C      T      T      C      C      C      C      G      T
## 10      C      T      T      C      C      C      C      G      T
## 11      G      T      T      C      C      C      C      G      T
## 12      G      T      T      C      C      C      C      G      T
## 13      G      T      T      C      C      C      C      G      T
## 14      G      T      T      C      C      C      C      G      T
## 15      C      T      T      C      C      C      C      G      T
## 16      C      T      T      C      C      C      C      G      T
## 17      C      T      T      C      C      C      C      G      T
## 18      C      T      T      C      C      C      C      G      T
## 19      C      T      T      C      C      C      C      G      T
## 20      C      T      T      C      C      C      C      G      T
## 21      C      T      T      C      C      C      C      G      T
## 22      C      T      T      C      C      C      C      G      T
## 23      C      T      T      C      C      C      C      G      T
## 24      C      T      T      C      C      C      C      G      T
## 25      C      T      T      C      C      C      C      G      T
## 26      C      T      T      C      C      C      C      G      T
## 27      C      T      T      C      C      C      C      G      T

```

```

## 28      C      T      T      C      C      C      C      C      G      T
## 29      C      T      T      C      C      C      C      C      G      T
## 30      C      T      T      C      C      C      C      C      G      T
## 31      C      T      T      C      C      C      C      C      G      T
## 32      C      T      T      C      C      C      C      C      G      T
## 33      C      T      T      C      C      C      C      C      G      T
## 34      C      T      T      C      C      C      C      C      G      T
## 35      C      T      T      C      C      C      C      C      G      T
## 36      C      T      T      C      C      C      C      C      G      T
## 37      C      T      T      C      C      C      C      C      G      T
## 38      C      T      T      C      C      C      C      C      G      T
## 39      C      T      T      C      C      C      C      C      G      T
## 40      C      T      T      C      C      C      C      C      G      T
## 41      C      T      T      C      C      C      C      C      G      T

##   loc-145 loc-146 loc-147 loc-148 loc-149 loc-150 loc-151 loc-152 loc-153
## 1      C      A      A      C      C      C      C      A      C
## 2      C      A      A      C      C      C      C      A      C
## 3      C      A      A      C      C      C      C      A      C
## 4      C      A      A      C      C      C      C      A      C
## 5      C      A      A      C      C      C      C      A      C
## 6      C      A      A      C      C      C      C      A      C
## 7      C      A      A      C      C      C      C      A      C
## 8      C      A      A      C      C      C      C      A      C
## 9      C      A      A      C      C      C      C      A      C
## 10     C      A      A      C      C      C      C      A      C
## 11     C      A      A      C      C      C      C      A      C
## 12     C      A      A      C      C      C      C      A      C
## 13     C      A      A      C      C      C      C      A      C
## 14     C      A      A      C      C      C      C      A      C
## 15     C      A      A      C      C      C      C      A      C
## 16     C      A      A      C      C      C      C      A      C
## 17     C      A      A      C      C      C      C      A      C
## 18     C      A      A      C      C      C      C      A      C
## 19     C      A      A      C      C      C      C      A      C
## 20     C      A      A      C      C      C      C      A      C
## 21     C      A      A      C      C      C      C      A      C
## 22     C      A      A      C      C      C      C      A      C
## 23     C      A      A      C      C      C      C      A      C
## 24     C      A      A      C      C      C      C      A      C
## 25     C      A      A      C      C      C      C      A      C
## 26     C      A      A      C      C      C      C      A      C
## 27     C      A      A      C      C      C      C      A      C
## 28     C      A      A      C      C      C      C      A      C
## 29     C      A      A      C      C      C      C      A      C
## 30     C      A      A      C      C      C      C      A      C
## 31     C      A      A      C      C      C      C      A      C
## 32     C      A      A      C      C      C      C      A      C
## 33     C      A      A      C      C      C      C      A      C
## 34     C      A      A      C      C      C      C      A      C
## 35     C      A      A      C      C      C      C      A      C
## 36     C      A      A      C      C      C      C      A      C
## 37     C      A      A      C      C      C      C      A      C
## 38     C      A      A      C      C      C      C      A      C
## 39     C      A      A      C      C      C      C      A      C

```

```

## 40      C      A      A      C      C      C      C      A      C
## 41      C      A      A      C      C      C      C      A      C
##    loc-154 loc-155 loc-156 loc-157 loc-158 loc-159 loc-160 loc-161 loc-162
## 1       A      G      G      C      G      C      G      T      A
## 2       A      G      G      C      G      C      G      T      A
## 3       A      G      G      C      G      C      G      T      A
## 4       A      G      G      C      G      C      G      T      A
## 5       A      G      G      C      G      C      G      T      A
## 6       A      G      G      C      G      C      G      T      A
## 7       A      G      G      C      G      T      G      C      T
## 8       A      G      G      C      G      C      G      C      T
## 9       A      G      G      C      G      C      G      C      T
## 10      A      G      G      C      G      C      G      C      T
## 11      A      G      G      C      G      C      G      C      T
## 12      A      G      G      C      G      C      G      C      T
## 13      A      G      G      C      G      C      G      C      T
## 14      A      G      G      C      G      C      G      C      T
## 15      A      G      G      C      G      C      G      C      T
## 16      A      G      G      C      G      T      G      C      T
## 17      A      G      G      C      G      T      G      C      T
## 18      A      G      G      C      G      C      G      T      A
## 19      A      G      G      C      G      C      G      T      A
## 20      A      G      G      C      G      C      G      T      A
## 21      A      G      G      C      G      C      G      T      A
## 22      A      G      G      C      G      C      G      T      A
## 23      A      G      G      C      G      C      G      T      A
## 24      A      G      G      C      G      C      G      T      A
## 25      A      G      G      C      G      C      G      T      A
## 26      A      G      G      C      G      C      G      T      A
## 27      A      G      G      C      G      C      G      T      A
## 28      A      G      G      C      G      C      G      T      A
## 29      A      G      G      C      G      T      G      C      T
## 30      A      G      G      C      G      C      G      T      A
## 31      A      G      G      C      G      C      G      T      A
## 32      A      G      G      C      G      C      G      T      A
## 33      A      G      G      C      G      C      G      T      A
## 34      A      G      G      C      G      C      G      T      A
## 35      A      G      G      C      G      C      G      T      A
## 36      A      G      G      C      G      C      G      T      A
## 37      A      G      G      C      G      C      G      C      T
## 38      A      G      G      C      G      C      G      T      A
## 39      A      G      G      C      G      C      G      T      A
## 40      A      G      G      C      G      T      G      C      T
## 41      A      G      G      C      G      C      G      T      A
##    loc-163 hap.freq
## 1       G  0.00467
## 2       G  0.00467
## 3       G  0.00422
## 4       G  0.00344
## 5       G  0.04012
## 6       G  0.00050
## 7       A  0.00467
## 8       A  0.00467
## 9       A  0.06325

```

```

## 10      A  0.00041
## 11      A  0.01869
## 12      A  0.00467
## 13      A  0.04673
## 14      A  0.00467
## 15      A  0.00467
## 16      A  0.01869
## 17      A  0.00467
## 18      G  0.00913
## 19      G  0.00467
## 20      G  0.04632
## 21      G  0.00435
## 22      G  0.00467
## 23      G  0.01588
## 24      G  0.00758
## 25      G  0.00467
## 26      G  0.00534
## 27      G  0.00400
## 28      G  0.00378
## 29      G  0.00760
## 30      G  0.05770
## 31      G  0.04879
## 32      G  0.00467
## 33      G  0.02804
## 34      G  0.00467
## 35      G  0.00467
## 36      G  0.03116
## 37      A  0.06718
## 38      G  0.01487
## 39      G  0.00820
## 40      G  0.01109
## 41      G  0.36750
## =====
##                               Details
## =====
## lnlike = -472.8509
## lr stat for no LD = 2838.267 , df = -3 , p-val = NA

```

There are 163 haplotypes possibles. The most frequent is number 6.

```

bim_file <- "APOE/APOE.bim"
bim_data <- read.table(bim_file, header = FALSE, stringsAsFactors = FALSE)

genotype_matrix <- data[,-1]
for (col in colnames(genotype_matrix)) {
  genotype_matrix[[col]] <- genotype(genotype_matrix[[col]])
}
calculate_MAF <- function(genotype_counts) {
  allele1 <- 2 * genotype_counts[[1]] + genotype_counts[[2]]
  allele2 <- 2 * genotype_counts[[3]] + genotype_counts[[2]]
  return (min(allele1, allele2) / (allele2 + allele1))
}

```

```

filter_index_MAF <- c()
res <- 0
for (i in 1:ncol(genotype_matrix)) {
  alleles <- c(paste(bim_data$V5[[i]], "/", bim_data$V6[[i]], sep = ""))
  count_gentotype <- MakeCounts(genotype_matrix[[i]], alleles = alleles, sep="/")
  MAF <- calculate_MAF(count_gentotype)
  if (MAF < 0.1) {
    filter_index_MAF <- c(filter_index_MAF, i)
  }
}
filter_index_MAF <- filter_index_MAF + 1
tmp1 <- 2 * filter_index_MAF
tmp2 <- 2 * filter_index_MAF + 1
filter_index_MAF <- cbind(tmp1, tmp2)
Geno_filtered <- Geno[, -filter_index_MAF]
print(haplo.em(Geno_filtered))

```

Question 4

```

## =====
##                               Haplotypes
## =====

##   loc-1 loc-2 loc-3 loc-4 loc-5 loc-6 loc-7 loc-8 loc-9 loc-10 loc-11 loc-12
## 1     2     C     A     C     C     G     T     C     T     A     G     C
## 2     2     C     G     C     C     G     T     C     T     A     G     T
## 3     2     G     G     T     T     A     C     A     C     G     T     C
## 4     2     G     G     T     T     A     C     A     C     G     T     T
## 5     2     G     G     T     T     A     C     A     C     G     T     T
## 6     N     C     C     G     A     C     G     C     C     C     T     T
## 7     N     C     C     G     C     C     G     C     C     C     T     C
## 8     N     C     C     G     C     C     G     C     C     C     T     C
## 9     N     C     C     G     C     C     G     C     C     C     T     T
## 10    N     C     C     G     C     C     G     C     C     C     T     T
## 11    N     C     C     G     C     C     G     C     C     C     T     T
## 12    N     C     C     G     C     C     G     C     C     C     T     T
## 13    N     G     C     G     C     C     G     C     C     C     T     T
##   loc-13 loc-14 loc-15 loc-16 loc-17 loc-18 loc-19 loc-20 loc-21 loc-22
## 1     T     G     A     T     A     C     A     C     T     A
## 2     T     G     T     T     A     C     A     C     T     A
## 3     C     T     T     G     A     T     C     T     T     A
## 4     C     G     T     T     A     C     A     C     T     G
## 5     C     T     T     G     C     T     C     T     A     G
## 6     A     G     A     T     C     G     T     A     A     G
## 7     A     G     A     T     A     G     T     A     T     A
## 8     T     G     A     T     A     G     T     A     T     A
## 9     A     G     A     T     A     G     T     A     T     A
## 10    A     G     A     T     A     G     T     A     T     G
## 11    A     G     A     T     C     G     T     A     A     G
## 12    T     G     A     T     C     G     T     A     T     A
## 13    A     G     A     T     C     G     T     A     A     G
##   hap.freq
## 1  0.00467
## 2  0.02336
## 3  0.00000

```

```

## 4 0.00935
## 5 0.46262
## 6 0.00467
## 7 0.02336
## 8 0.00467
## 9 0.11215
## 10 0.00935
## 11 0.26636
## 12 0.07477
## 13 0.00467
## =====
##          Details
## =====
## lnlike = -249.2797
## lr stat for no LD = 752.5871 , df = -21 , p-val = NA

```

There are only 22 haplotypes and the most frequent is number 5.

Excluding genetic variants with a minor allele frequency (MAF) below 0.10 led to a significant reduction in the number of identified haplotypes, from 163 to 22. This reduction reflects a focus on more common variants in the population, excluding those with lower frequencies. The decrease suggests a loss of genetic diversity, as the excluded haplotypes were likely associated with less common variants in the studied population. The choice of the MAF threshold is crucial and may impact haplotype analysis outcomes, highlighting the need for careful consideration based on the study's objectives.