# Lab: Week 4 – Solutions

36-350 – Statistical Computing

Week 4 – Spring 2021

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## Apply: Base R

You are given the following $8 \times 8$ matrix:

```
set.seed(1001)
mat = matrix(rnorm(64),nrow=8)
mat[5,8] = mat[6,7] = mat[4,2] = NA
```

### Question 1

*Notes 4A (6,10,12)*

Compute the mean for each row and for each column using both `apply()` *and* either `rowMeans()` or `colMeans()`. (So there should be four function calls overall.) Deal with the `NA`s by passing (an) additional argument(s) to these functions, when possible.

```
apply(mat,MARGIN=1,FUN=mean,na.rm=TRUE)
```

```
## [1]  0.29520657  0.51323956 -0.46939506 -0.46438383 -0.19427723  0.02530351
## [7]  0.06268717  0.16192061
```

```
rowMeans(mat,na.rm=TRUE)
```

```
## [1]  0.29520657  0.51323956 -0.46939506 -0.46438383 -0.19427723  0.02530351
## [7]  0.06268717  0.16192061
```

```
apply(mat,MARGIN=2,FUN=mean,na.rm=TRUE)
```

```
## [1] -0.1141279 -0.1176691 0.3097320 -0.3976337 0.2625528 -0.1828815
0.0382058
## [8] 0.2301255
```

```
colMeans(mat,na.rm=TRUE)
```

```
## [1] -0.1141279 -0.1176691 0.3097320 -0.3976337 0.2625528 -0.1828815
0.0382058
## [8] 0.2301255
```

### Question 2

*Function writing review*

How does the `Income` variable in `R`'s `state.x77` matrix correlate with other variables? Write a function called `cor_var()` that takes two inputs: `v1`, a numeric vector; and `v2`, another numeric vector whose default value is `state.x77[,"Income"]`. Its output should be the correlation of `v1` and `v2`, computed

via the `cor()` function. Check that `cor_var(v1=state.x77[,"Life Exp"])` gives you 0.3402553, and `cor_var(v1=state.x77[,"Income"])` gives you 1.

```
cor_var = function(v1,v2=state.x77[,"Income"]) { cor(v1,v2) }
cor_var(v1=state.x77[,"Life Exp"])
```

```
## [1] 0.3402553
```

```
cor_var(v1=state.x77[,"Income"])
```

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

### Question 3

*Notes 4A (6-7,9-10)*

Using `apply()` and the function `cor_var()` that you defined in the last question, calculate the correlation between each one of the 8 variables in the `state.x77` matrix and the `Population` variable. Display these correlations.

```
apply(state.x77,MARGIN=2,FUN=cor_var,v2=state.x77[,"Population"])
```

```
##  Population      Income  Illiteracy    Life Exp      Murder     HS Grad
##  1.00000000  0.20822756  0.10762237 -0.06805195  0.34364275 -0.09848975
##       Frost        Area
## -0.33215245  0.02254384
```

### Question 4

*Notes 4A (6,10)*

Using `apply()` and the base `R stats` package function `cor()`, display the Spearman correlation between each one of the eight variables in the `state.x77` matrix and the `Frost` variable. (Note that `Spearman` is not the default value for the `method` argument to the `cor()` function.)

```
apply(state.x77,MARGIN=2,FUN=cor,y=state.x77[,"Frost"],method="kendall")
```

```
##  Population      Income  Illiteracy    Life Exp      Murder     HS Grad
## -0.30454484  0.13098703 -0.53610593  0.22213145 -0.41362334  0.29262334
##       Frost        Area
##  1.00000000  0.05403215
```

## Variations on Apply: Base R

### Question 5

*Notes 4B (6)*

Create a data frame called `state.df` from the matrix `state.x77` and the factors `state.region` and `state.division`. Be sure to name the two new columns appropriately. Using `state.df` and `tapply()`, compute the average population in each of the four defined regions of the U.S. Display the name of the region has the largest average population (and only that name). Then compute the average population in each of the nine defined divisions of the U.S., and display the name of the division has the largest average population (and only that name). Hint: the names may be displayed using a combination of `names()` and `which.max()`.

```
state.df = data.frame(state.x77,Region=state.region,Division=state.division)
(population.by.reg = tapply(state.df$Population,INDEX=state.df$Region,FUN=mean))
```

```
##     Northeast         South North Central          West
```

```
##      5495.111      4208.125      4803.000      2915.308
```

```
(population.by.div = tapply(state.df$Population,INDEX=state.df$Division,FUN=mean))
```

```
##        New England    Middle Atlantic     South Atlantic East South Central
##           2031.167          12423.000           4118.250           3379.000
## West South Central East North Central West North Central           Mountain
##           5217.000           8189.000           2384.429           1203.125
##            Pacific
##           5654.800
```

```
names(population.by.reg)[which.max(population.by.reg)]
```

```
## [1] "Northeast"
```

```
names(population.by.div)[which.max(population.by.div)]
```

```
## [1] "Middle Atlantic"
```

## Question 6

*Notes 4A (5) and Notes 4B (3-4)*

Split the rows of the data frame `state.df` by state divisions, and call the resulting list `state.df.by.div`. Then use `lapply()` to display just the first two rows of each data frame in the list `state.df.by.div`.

```
state.df.by.div = split(state.df,f=state.df$Division)
lapply(state.df.by.div,head,2)
```

```
## $`New England`
##             Population Income Illiteracy Life.Exp Murder HS.Grad Frost  Area
## Connecticut       3100   5348        1.1    72.48    3.1    56.0   139  4862
## Maine             1058   3694        0.7    70.39    2.7    54.7   161 30920
##                Region    Division
## Connecticut Northeast New England
## Maine       Northeast New England
##
## $`Middle Atlantic`
##            Population Income Illiteracy Life.Exp Murder HS.Grad Frost  Area
## New Jersey       7333   5237        1.1    70.93    5.2    52.5   115  7521
## New York        18076   4903        1.4    70.55   10.9    52.7    82 47831
##               Region        Division
## New Jersey Northeast Middle Atlantic
## New York   Northeast Middle Atlantic
##
## $`South Atlantic`
##          Population Income Illiteracy Life.Exp Murder HS.Grad Frost  Area
## Delaware        579   4809        0.9    70.06    6.2    54.6   103  1982
## Florida        8277   4815        1.3    70.66   10.7    52.6    11 54090
##          Region       Division
## Delaware  South South Atlantic
## Florida   South South Atlantic
##
## $`East South Central`
##          Population Income Illiteracy Life.Exp Murder HS.Grad Frost  Area
## Alabama        3615   3624        2.1    69.05   15.1    41.3    20 50708
## Kentucky       3387   3712        1.6    70.10   10.6    38.5    95 39650
```

```
##          Region           Division
## Alabama   South East South Central
## Kentucky  South East South Central
##
## $`West South Central`
##           Population Income Illiteracy Life.Exp Murder HS.Grad Frost  Area
## Arkansas        2110   3378        1.9    70.66   10.1    39.9    65 51945
## Louisiana       3806   3545        2.8    68.76   13.2    42.2    12 44930
##           Region           Division
## Arkansas   South West South Central
## Louisiana  South West South Central
##
## $`East North Central`
##          Population Income Illiteracy Life.Exp Murder HS.Grad Frost  Area
## Illinois      11197   5107        0.9    70.14   10.3    52.6   127 55748
## Indiana        5313   4458        0.7    70.88    7.1    52.9   122 36097
##                 Region           Division
## Illinois North Central East North Central
## Indiana  North Central East North Central
##
## $`West North Central`
##        Population Income Illiteracy Life.Exp Murder HS.Grad Frost  Area
## Iowa         2861   4628        0.5    72.56    2.3    59.0   140 55941
## Kansas       2280   4669        0.6    72.58    4.5    59.9   114 81787
##               Region           Division
## Iowa   North Central West North Central
## Kansas North Central West North Central
##
## $Mountain
##          Population Income Illiteracy Life.Exp Murder HS.Grad Frost   Area
## Arizona        2212   4530        1.8    70.55    7.8    58.1    15 113417
## Colorado       2541   4884        0.7    72.06    6.8    63.9   166 103766
##          Region Division
## Arizona    West Mountain
## Colorado   West Mountain
##
## $Pacific
##            Population Income Illiteracy Life.Exp Murder HS.Grad Frost   Area
## Alaska            365   6315        1.5    69.31   11.3    66.7   152 566432
## California      21198   5114        1.1    71.71   10.3    62.6    20 156361
##            Region Division
## Alaska       West  Pacific
## California   West  Pacific
```

---

Below, we read in a data table showing the fastest women's 100-meter sprint times.

```
sprint.df = read.table("http://www.stat.cmu.edu/~mfarag/350/women_100m_with_header.dat",header=TRUE,str
class(sprint.df)
```

```
## [1] "data.frame"
```

```
head(sprint.df)
```

```
##   Rank  Time Wind First.Name       Last.Name Country Birthdate Race
```

```
## 1    1 10.49  0.0   Florence Griffith-Joyner     USA  21.12.59  1q1
## 2    2 10.61  1.2   Florence Griffith-Joyner     USA  21.12.59    1
## 3    3 10.62  1.0   Florence Griffith-Joyner     USA  21.12.59  1q3
## 4    4 10.64  1.2  Carmelita           Jeter     USA  24.11.79    1
## 5    5 10.65  1.1     Marion           Jones     USA  12.10.75    1
## 6    6 10.67 -0.1  Carmelita           Jeter     USA  24.11.79    1
##       Location       Date
## 1 Indianapolis 16.07.1988
## 2 Indianapolis 17.07.1988
## 3        Seoul 24.09.1988
## 4     Shanghai 20.09.2009
## 5 Johannesburg 12.09.1998
## 6 Thessaloniki 13.09.2009
```

---

## Question 7

*Review of string processing*

Extract the last four digits of each entry of the `Date` column. (Hint: you will have to use `as.character()` to convert `sprint.df$Date` from a factor variable to strings.) Create a new data frame called `new.sprint.df` that combines `sprint.df` and a new column called `Year` that contains your extracted four-digit years. Display the first five rows and all 11 columns of `new.sprint.df`. Display the class of the newly created `Year` column.

```
d = sprint.df$Date
year.str  = substr(d,nchar(d)-3,nchar(d))
new.sprint.df = data.frame(sprint.df,Year=year.str)
head(new.sprint.df,5)
```

```
##   Rank  Time Wind First.Name       Last.Name Country Birthdate Race
## 1    1 10.49  0.0   Florence Griffith-Joyner     USA  21.12.59  1q1
## 2    2 10.61  1.2   Florence Griffith-Joyner     USA  21.12.59    1
## 3    3 10.62  1.0   Florence Griffith-Joyner     USA  21.12.59  1q3
## 4    4 10.64  1.2  Carmelita           Jeter     USA  24.11.79    1
## 5    5 10.65  1.1     Marion           Jones     USA  12.10.75    1
##       Location       Date Year
## 1 Indianapolis 16.07.1988 1988
## 2 Indianapolis 17.07.1988 1988
## 3        Seoul 24.09.1988 1988
## 4     Shanghai 20.09.2009 2009
## 5 Johannesburg 12.09.1998 1998
```

```
class(new.sprint.df$Year)
```

```
## [1] "character"
```

## Question 8

*Notes 4B (6)*

Using `tapply()` and the newly created `Year` column, compute the median 100-meter sprint time in each year of the data frame. Call the resulting vector `med.time.by.year`. Create a table of median times. Which median time appears the most, and how many times does it appear? When is the last year that that particular median time appeared in the data?

```
med.time.by.year = tapply(new.sprint.df$Time,INDEX=new.sprint.df$Year,FUN=median)
table(med.time.by.year)
```

```
## med.time.by.year
##  10.98  10.99 10.995     11 11.005  11.01 11.015  11.02  11.03 11.035  11.04
##      1      1      1      6      1      5      2      4      7      1      7
## 11.045  11.05 11.055  11.06  11.07  11.08
##      1      2      1      2      2      1
```

```
med.time.by.year
```

```
##   1968   1972   1973   1976   1977   1978   1979   1980   1981   1982   1983
## 11.080 11.070 11.070 11.055 11.030 11.050 11.040 11.060 11.040 11.010 11.035
##   1984   1985   1986   1987   1988   1989   1990   1991   1992   1993   1994
## 10.990 11.010 11.030 11.040 11.000 11.040 11.050 10.995 10.980 11.000 11.015
##   1995   1996   1997   1998   1999   2000   2001   2002   2003   2004   2005
## 11.040 11.000 11.030 11.010 11.020 11.030 11.020 11.020 11.045 11.030 11.030
##   2006   2007   2008   2009   2010   2011   2012   2013   2014   2015   2016
## 11.060 11.040 11.020 11.010 11.015 11.000 11.000 11.000 11.030 11.010 11.005
##   2017
## 11.040
```

```
11.04 seconds appears seven times in the data. This median time last occurred in 2017.
```

---

Below, we read in a data table related to the political economy of strikes.

```
strikes.df = read.csv("http://www.stat.cmu.edu/~mfarag/350/strikes.csv")
class(strikes.df)
```

```
## [1] "data.frame"
```

```
head(strikes.df)
```

```
##     country year strike.volume unemployment inflation left.parliament
## 1 Australia 1951           296          1.3      19.8            43.0
## 2 Australia 1952           397          2.2      17.2            43.0
## 3 Australia 1953           360          2.5       4.3            43.0
## 4 Australia 1954             3          1.7       0.7            47.0
## 5 Australia 1955           326          1.4       2.0            38.5
## 6 Australia 1956           352          1.8       6.3            38.5
##   centralization density
## 1      0.3748588      NA
## 2      0.3751829      NA
## 3      0.3745076      NA
## 4      0.3710170      NA
## 5      0.3752675      NA
## 6      0.3716072      NA
```

```
dim(strikes.df) # Note that since 18 × 35 = 630 > 625, some years missing from some countries
```

```
## [1] 625   8
```

---

## Question 9

*Notes 4A (5) and Notes 4B (5)*

Split `strikes.df` by country, using the `split()` function. Call the resulting list `strikes.by.country`.

Using `strikes.by.country` and `sapply()`, compute the average centralization metric (a quantity related to unionization) for each country over the range of years in the file. Display the names of the countries that had the highest and lowest average centralization metric (and only the names of those countries).

```
strikes.by.country = split(strikes.df,strikes.df$country)
sapply.out = sapply(strikes.by.country,function(df)mean(df$centralization))
cat("Maximum was in ",names(sapply.out)[which.max(sapply.out)],".\n",sep="")
```

```
## Maximum was in Austria.
```

```
cat("Minimum was in ",names(sapply.out)[which.min(sapply.out)],".\n",sep="")
```

```
## Minimum was in Canada.
```

## Question 10

*Notes 4B (5)*

Using `strikes.by.country` and `sapply()`, compute a summary of the long-term centralization metric for each country. Study the output—do its dimensions make sense to you?

```
sapply(strikes.by.country, function(df)summary(df$centralization))
```

```
##         Australia   Austria   Belgium       Canada   Denmark   Finland
## Min.    0.3701921 0.9951362 0.7451018 4.985230e-06 0.4951243 0.7453985
## 1st Qu. 0.3723613 0.9963630 0.7480245 8.232258e-04 0.4971313 0.7486803
## Median  0.3745076 0.9977592 0.7489699 2.206919e-03 0.5003940 0.7501793
## Mean    0.3746440 0.9976705 0.7494852 2.244134e-03 0.4999586 0.7503741
## 3rd Qu. 0.3763172 0.9988332 0.7514769 3.468929e-03 0.5022077 0.7521806
## Max.    0.3798597 0.9997884 0.7544044 4.849537e-03 0.5048790 0.7549842
##               France   Germany   Ireland     Italy     Japan Netherlands
## Min.    0.0002446096 0.2453393 0.4951136 0.2454353 0.1205130   0.7454194
## 1st Qu. 0.0013202927 0.2477310 0.4974278 0.2490072 0.1233528   0.7474436
## Median  0.0028737475 0.2493486 0.4994846 0.2507560 0.1247869   0.7491107
## Mean    0.0027299088 0.2499682 0.4997119 0.2506995 0.1246753   0.7496027
## 3rd Qu. 0.0042529214 0.2524444 0.5022122 0.2527474 0.1261252   0.7520595
## Max.    0.0049236913 0.2548710 0.5048117 0.2547880 0.1297671   0.7540260
##         New.Zealand    Norway    Sweden Switzerland        UK         USA
## Min.      0.3706028 0.8700540 0.8701569   0.4956250 0.3701746 0.000109027
## 1st Qu.   0.3730609 0.8730289 0.8723843   0.4976971 0.3738972 0.001355673
## Median    0.3761876 0.8750384 0.8756796   0.4993706 0.3756106 0.002406464
## Mean      0.3759404 0.8753418 0.8752538   0.4999900 0.3759468 0.002390639
## 3rd Qu.   0.3786986 0.8780262 0.8778525   0.5024074 0.3785299 0.003252352
## Max.      0.3798821 0.8799584 0.8794025   0.5048787 0.3797725 0.004975356
```

```
When the output of the function is always of the same length,
then sapply()'s output will be simplified to a matrix.
Summary has six outputs, so sapply()'s output has six rows.
```

## Question 11

*Notes 4B (5)*

Using `strikes.by.country` and just *one* call to `sapply()`, compute the average unemployment rate, average inflation rate, and average strike volume for each country. The output should be a matrix of dimension 3 x 18. Also, within that call, give the output matrix appropriate row names.

```r
sapply(strikes.by.country,function(df) {
  c("Unemployment Average"=mean(df$unemployment),
    "Inflation Average"=mean(df$inflation),
    "Strike Average"=mean(df$strike.volume))
})
```

```
##                       Australia   Austria    Belgium     Canada    Denmark
## Unemployment Average   3.505714  2.540000   3.646667   6.042857   5.711429
## Inflation Average      6.594286  5.102857   4.150000   4.797143   6.582857
## Strike Average       378.600000 25.600000 244.000000 749.542857 194.828571
##                         Finland     France   Germany    Ireland      Italy
## Unemployment Average   2.571429   3.182857  3.117143   7.771429   6.725714
## Inflation Average      7.317143   6.948571  3.294286   8.151429   8.005714
## Strike Average       448.542857 185.400000 43.828571 547.428571 997.685714
##                            Japan Netherlands New.Zealand    Norway    Sweden
## Unemployment Average   1.602857    3.691429    1.002857  1.428571  2.137143
## Inflation Average      5.820000    4.814286    7.691429  6.320000  6.434286
## Strike Average       165.828571   26.114286  259.257143 75.114286 73.485714
##                      Switzerland         UK        USA
## Unemployment Average   0.3285714   3.451429   5.542857
## Inflation Average      3.4171429   7.105714   4.428571
## Strike Average         3.6571429 322.714286 448.228571
```

## Question 12

*Notes 4B (5)*

Using `strikes.df`, `split()`, and `sapply()`, compute the average unemployment rate for each country, before and during 1970, and after 1970. Display the output; it should be a numeric vector of length 36. One way to perform the splitting is to define a new column called `pre1970` that indicates that a year column is less than or equal to 1970. Then use both `country` *and* `pre1970` to do the splitting. If you are not sure how to use both factor variables at once, look at the documentation for `split()`, specifically its argument `f`.

```r
strikes.df$pre1970 = strikes.df$year<=1970
(unemp.vec = sapply(split(strikes.df,list(strikes.df$country,strikes.df$pre1970)),
                    function(df)mean(df$unemployment)))
```

```
##   Australia.FALSE     Austria.FALSE     Belgium.FALSE      Canada.FALSE
##         5.5066667         2.1000000         4.7700000         8.0000000
##     Denmark.FALSE     Finland.FALSE      France.FALSE     Germany.FALSE
##         6.2800000         4.3266667         5.6800000         4.1933333
##     Ireland.FALSE       Italy.FALSE       Japan.FALSE Netherlands.FALSE
##         9.2200000         7.3200000         2.0000000         6.7800000
## New.Zealand.FALSE      Norway.FALSE      Sweden.FALSE Switzerland.FALSE
##         2.0066667         1.9933333         2.4000000         0.3866667
##          UK.FALSE         USA.FALSE    Australia.TRUE      Austria.TRUE
##         6.1333333         6.9466667         2.0050000         2.8700000
##      Belgium.TRUE       Canada.TRUE      Denmark.TRUE      Finland.TRUE
##         3.0850000         4.5750000         5.2850000         1.2550000
##       France.TRUE      Germany.TRUE      Ireland.TRUE        Italy.TRUE
##         1.3100000         2.3100000         6.6850000         6.2800000
##        Japan.TRUE  Netherlands.TRUE  New.Zealand.TRUE       Norway.TRUE
##         1.3050000         1.3750000         0.2500000         1.0050000
##       Sweden.TRUE  Switzerland.TRUE           UK.TRUE          USA.TRUE
##         1.9400000         0.2850000         1.4400000         4.4900000
```

## Question 13

*Review of matrices*

Using the result from above, display the difference in the average unemployment rate before and after 1970 for each country. (To be clear: subtract the pre-1970 results from the post-1970 results.) Which country had the biggest increase in average unemployment from before to after? The biggest decrease? (Hint: use the output from Q12 to populate a matrix, with pre-1970 results in one column and post-1970 results in another.)

```
unemp.mat = matrix(unemp.vec,ncol=2)
unemp.diff = unemp.mat[,1]-unemp.mat[,2]
names(unemp.diff) = unique(strikes.df$country)
unemp.diff
```

```
##   Australia     Austria     Belgium      Canada     Denmark     Finland
##   3.5016667  -0.7700000   1.6850000   3.4250000   0.9950000   3.0716667
##      France     Germany     Ireland       Italy       Japan Netherlands
##   4.3700000   1.8833333   2.5350000   1.0400000   0.6950000   5.4050000
## New.Zealand      Norway      Sweden Switzerland          UK         USA
##   1.7566667   0.9883333   0.4600000   0.1016667   4.6933333   2.4566667
```

```
names(unemp.diff)[which.max(unemp.diff)]
```

```
## [1] "Netherlands"
```

```
names(unemp.diff)[which.min(unemp.diff)]
```

```
## [1] "Austria"
```

---

## Question 14

*Pipes + Notes 4D (6)*

How does the `Frost` variable in R's `state.x77` matrix correlate with other variables? Cast `state.x77` to a data frame, and, using pipes, generate the correlation matrix for `Frost` and `Life.Exp`. (Note that the act of casting changed the name of the life expectancy column from `Life Exp` to `Life.Exp`.) The off-diagonal elements of the matrix should be 0.262068.

```
suppressWarnings(suppressMessages(library(dplyr)))
data.frame(state.x77) %>% select("Life.Exp","Frost") %>% cor()
```

```
##          Life.Exp    Frost
## Life.Exp 1.000000 0.262068
## Frost    0.262068 1.000000
```

## Question 15

*Pipes + Notes 4D (9)*

Take the `state.df` data frame defined in Q5 above and mutate it so as to create a new column: `GradLit`. This column should have, for each row in the data frame, the percentage of high school graduates divided by the percentage of literate (note: *literate*, not *illiterate*) individuals, times 100. Then pipe the output so as to compute the median value of `GradLit`. (There is a bit of weirdness here: due to environmental issues, your call to `median()` will not work unless it is placed within curly braces. You are only surrounding `median()` with curly braces... not the entire pipe stream!) Your final value should be 53.59844.

```
state.df %>% mutate(GradLit=100*HS.Grad/(100-Illiteracy)) %>% {median(.$GradLit)}
```

```
## [1] 53.59844
```

## Question 16

*Pipes + Notes 4D (5,6,8)*

Take the `state.df` data frame and (1) select all states in the South region, and (2) display the result ordered by the decreasing product of income and life expectancy. In the end, display just the state name and the computed product. There is a quirk here: selecting rows can lead to the loss of row names. (This means that here, you will have a final result but not know which states they correspond to.) To preserve the identity of the states, pipe `state.df` to the function `rownames_to_column("give column name here, like State")`, then do the rest of your piping.

```
suppressWarnings(suppressMessages(library(tidyverse)))
state.df %>% rownames_to_column("State") %>% filter(Region=="South") %>%
mutate(ILE=Income*Life.Exp) %>% select(State,ILE) %>% arrange(desc(ILE))
```

```
##             State      ILE
## 1        Maryland 372095.8
## 2         Florida 340227.9
## 3        Delaware 336918.5
## 4        Virginia 329446.1
## 5           Texas 296929.2
## 6        Oklahoma 284465.9
## 7         Georgia 280397.1
## 8  North Carolina 268188.8
## 9       Tennessee 267890.3
## 10       Kentucky 260211.2
## 11  West Virginia 251309.2
## 12        Alabama 250237.2
## 13 South Carolina 247034.6
## 14      Louisiana 243754.2
## 15       Arkansas 238689.5
## 16    Mississippi 210942.8
```