

Ch3. Matrices

Jongrak Jeong

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1. Matrix

Define the matrix

```
n <- 100
p <- 3

x <- rnorm(n * p)
x[1:6]
```

```
## [1]  0.9993032 -0.4627079 -1.0764344 -0.5060978  0.3928347 -1.0772955
```

```
A <- matrix(x, nrow = n, ncol = p)
A[1:6,]
```

```
##           [,1]      [,2]      [,3]
## [1,]  0.9993032  0.2760604  0.07425916
## [2,] -0.4627079 -0.7567618  0.88695973
## [3,] -1.0764344 -0.9648463 -1.48145471
## [4,] -0.5060978 -1.0108694 -0.56075007
## [5,]  0.3928347  0.5641408 -1.04180912
## [6,] -1.0772955  1.0784003  1.04418303
```

Indexing and Filtering

Indexing

```
# ex1
A[1:5, 1:2]
```

```
##           [,1]      [,2]
## [1,]  0.9993032  0.2760604
## [2,] -0.4627079 -0.7567618
## [3,] -1.0764344 -0.9648463
## [4,] -0.5060978 -1.0108694
## [5,]  0.3928347  0.5641408
```

```
# ex2: n x 1
A[c(1, 3, 5), 1]
```

```
## [1]  0.9993032 -1.0764344  0.3928347
```

Filtering

```
# Filtering: find the rows satisfying 'first column > 0'  
A[A[,1] > 0,]
```

```
##           [,1]           [,2]           [,3]  
## [1,] 0.99930319 2.760604e-01 0.07425916  
## [2,] 0.39283467 5.641408e-01 -1.04180912  
## [3,] 1.63463231 -3.187879e-01 0.07071557  
## [4,] 0.10703670 9.989840e-01 0.60252799  
## [5,] 0.43178104 2.601567e-01 -0.24022708  
## [6,] 0.73219801 2.973174e-01 -0.69019022  
## [7,] 0.54192477 -2.088851e-01 0.93141261  
## [8,] 0.55154407 -1.633010e+00 0.14854951  
## [9,] 0.09213279 -7.086126e-01 -0.52065814  
## [10,] 1.38554826 3.603558e-01 -0.37312639  
## [11,] 1.02937210 -2.197066e-01 0.30892243  
## [12,] 0.93874213 8.099044e-02 -0.56264030  
## [13,] 1.35324200 1.349723e+00 0.87040573  
## [14,] 0.14995473 5.127059e-01 1.75836920  
## [15,] 1.99306996 8.536600e-01 0.88834746  
## [16,] 0.63688053 -5.289340e-01 0.69755046  
## [17,] 0.55308931 1.256935e-01 -1.65639387  
## [18,] 0.39792917 -9.810936e-01 -0.95410879  
## [19,] 0.53745626 -6.842200e-02 0.79292310  
## [20,] 0.32938765 9.624135e-01 -1.20988598  
## [21,] 0.25220176 -3.566166e+00 -0.60254180  
## [22,] 1.77075047 5.625676e-01 -0.70924897  
## [23,] 0.43948323 4.688219e-01 -0.89062532  
## [24,] 1.31391273 -8.091352e-01 0.66996962  
## [25,] 1.00993432 1.297803e+00 -0.01679276  
## [26,] 0.49429176 -4.585802e-01 -0.18453328  
## [27,] 1.78344049 2.176079e-05 1.72268828  
## [28,] 1.69336622 8.212741e-01 0.74370311  
## [29,] 1.73320249 -1.390464e-02 0.49538036  
## [30,] 0.63318243 -6.249869e-02 -0.09801899  
## [31,] 0.44652727 3.893611e-01 -0.96533253  
## [32,] 1.87074376 8.123949e-01 -0.56089240  
## [33,] 0.21631409 -1.774946e+00 0.88597681  
## [34,] 0.68681628 -1.885042e-01 -1.31242664  
## [35,] 1.66503111 -3.167783e+00 0.80471385  
## [36,] 1.59220415 4.674180e-01 -1.27860607  
## [37,] 0.40190755 4.864534e-01 1.09751661  
## [38,] 0.19233215 1.392619e+00 -0.12516199  
## [39,] 0.83155417 -1.215094e+00 0.22600595  
## [40,] 0.73768065 9.757071e-03 0.47242759  
## [41,] 0.84549886 -5.499664e-01 0.54096776  
## [42,] 0.00970867 -2.459021e+00 0.73802810  
## [43,] 1.28322633 5.192049e-01 -0.15887295  
## [44,] 2.04032398 -1.035281e+00 2.01215148  
## [45,] 0.19571024 4.264785e-01 0.23077603  
## [46,] 0.65943079 -2.479772e+00 0.51195926  
## [47,] 1.05841619 -1.235911e+00 -0.83404953
```

```
# Filtering: find the rows satisfying 'first column > 0 & second column > 0'
A[A[,1] > 0 & A[,2] > 0,]
```

```
##           [,1]      [,2]      [,3]
## [1,] 0.9993032 2.760604e-01 0.07425916
## [2,] 0.3928347 5.641408e-01 -1.04180912
## [3,] 0.1070367 9.989840e-01 0.60252799
## [4,] 0.4317810 2.601567e-01 -0.24022708
## [5,] 0.7321980 2.973174e-01 -0.69019022
## [6,] 1.3855483 3.603558e-01 -0.37312639
## [7,] 0.9387421 8.099044e-02 -0.56264030
## [8,] 1.3532420 1.349723e+00 0.87040573
## [9,] 0.1499547 5.127059e-01 1.75836920
## [10,] 1.9930700 8.536600e-01 0.88834746
## [11,] 0.5530893 1.256935e-01 -1.65639387
## [12,] 0.3293876 9.624135e-01 -1.20988598
## [13,] 1.7707505 5.625676e-01 -0.70924897
## [14,] 0.4394832 4.688219e-01 -0.89062532
## [15,] 1.0099343 1.297803e+00 -0.01679276
## [16,] 1.7834405 2.176079e-05 1.72268828
## [17,] 1.6933662 8.212741e-01 0.74370311
## [18,] 0.4465273 3.893611e-01 -0.96533253
## [19,] 1.8707438 8.123949e-01 -0.56089240
## [20,] 1.5922041 4.674180e-01 -1.27860607
## [21,] 0.4019076 4.864534e-01 1.09751661
## [22,] 0.1923322 1.392619e+00 -0.12516199
## [23,] 0.7376806 9.757071e-03 0.47242759
## [24,] 1.2832263 5.192049e-01 -0.15887295
## [25,] 0.1957102 4.264785e-01 0.23077603
```

Arithmetic operation

matrix addition: $A + B$ (same form)

multiplication of a scalar and matrix: $c * A$

element-wise product: $*$ (same size matrices)

division of matrix: $/$ (same size matrices)

transpose of matrix: $t(A)$ (nonsingular $p \times p$ matrix)

```
A <- matrix(6:1, 3, 2)
```

```
A
```

```
##           [,1] [,2]
## [1,]      6    3
## [2,]      5    2
## [3,]      4    1
```

```
t(A)
```

```
##           [,1] [,2] [,3]
## [1,]      6    5    4
## [2,]      3    2    1
```

inverse matrix: solve(C) (nonsingular p x p matrix)

```
C <- matrix(c(16, 4, 1, 4, 4, 1, 1, 1, 1), 3, 3)
```

```
C
```

```
##      [,1] [,2] [,3]
## [1,]   16    4    1
## [2,]    4    4    1
## [3,]    1    1    1
```

```
C_i <- solve(C)
```

matrix multiplication: A %*% B (# of A's columns = # of B's rows)

```
C_i %*% C
```

```
##      [,1]      [,2]      [,3]
## [1,] 1.000000e+00 -5.551115e-17 -1.387779e-17
## [2,] 1.665335e-16  1.000000e+00  5.551115e-17
## [3,] 0.000000e+00  0.000000e+00  1.000000e+00
```

2. applitcation: linear regrssion

```
# detailed version
```

```
set.seed(123)
```

```
n <- 100
```

```
x0 <- rep(1,n)
```

```
x1 <- rnorm(n)
```

```
x2 <- rnorm(n)
```

```
e <- rnorm(n)
```

```
y <- x1 - x2 + e
```

```
X <- cbind(x0, x1, x2)
```

```
b <- solve(t(X) %*% X) %*% (t(X) %*% y)
```

```
round(b, 5)
```

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

```
## x0  0.13507
```

```
## x1  0.86683
```

```
## x2 -0.97619
```

```
r <- y - X %*% b
```

```
y.1 <- y - mean(y)
```

```
R.squared <- 1 - sum(r * r) / sum(y.1 * y.1)
```

```
round(R.squared, 4)
```

```
## [1] 0.6422
```

```
# practical version
```

```
summary(lm(y ~ x1 + x2))
```

```
##
```

```
## Call:
```

```
## lm(formula = y ~ x1 + x2)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -1.8730 -0.6607 -0.1245  0.6214  2.0798
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  0.13507     0.09614   1.405   0.163
## x1           0.86683     0.10487   8.266 7.29e-13 ***
## x2          -0.97619     0.09899  -9.861 2.68e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.9513 on 97 degrees of freedom
## Multiple R-squared:  0.6422, Adjusted R-squared:  0.6348
## F-statistic: 87.03 on 2 and 97 DF,  p-value: < 2.2e-16

reg <- function(y, x1, x2) {
  X <- cbind(rep(1, length(y)), x1, x2)
  b <- solve(t(X) %*% X) %*% (t(X) %*% y)
  r <- y - X %*% b
  y.1 <- y - mean(y)
  R.squared <- 1 - sum(r * r) / sum(y.1 * y.1)
  return(list(beta = round(b, 5), R.squared = round(R.squared, 4)))
}

reg(y, x1, x2)

## $beta
##      [,1]
## 0.13507
## x1 0.86683
## x2 -0.97619
##
## $R.squared
## [1] 0.6422
```

3. matrix and apply() function

ex1: summation

```
# apply(matrix, row or column - 1 is for row and 2 is for column, function)
M <- matrix(sample(1:6), 3, 2)

M

##      [,1] [,2]
## [1,]    4    6
## [2,]    1    5
## [3,]    3    2

apply(M, 1, sum)

## [1] 10  6  5
```

```
apply(M, 2, sum)
```

```
## [1] 8 13
```

ex2: scaling - mean and sd standardization

```
n <- 100; set.seed(1)
X <- matrix(rnorm(n * 4), n, 4)

m <- apply(X, 2, mean)
s <- apply(X, 2, sd)

X.1 <- t(apply(X, 1, "-", m)) # X - m and then transpose
X.2 <- t(apply(X.1, 1, "/", s))

head(round(X.2, 2), 3)

##          [,1] [,2] [,3] [,4]
## [1,] -0.82 -0.61 0.37 0.85
## [2,] 0.08 0.08 1.60 -1.11
## [3,] -1.05 -0.91 1.51 1.94
# There's a built-in function 'scale()'
```

parctice 1: scaling - min and max standardization

```
X.1 <- t(apply(X, 1, "-", min(X)))
X.2 <- max(X) - min(X)
X.3 <- t(apply(X.1, 1, "/", X.2))
```

ex3: find second second smallest value (Monte-Carlo Method)

```
#  $x_1, \dots, x_p \sim U(0,1)$ . What is  $x(2)$ 
n <- 1000
p <- 10

# 1000 rows. each row contains 10 random numbers of uniform distribution.
M <- matrix(runif(n * p), n, p)

# apply 'sort' functions to M matrix by row
M.1 <- t(apply(M, 1, sort))
M.1

##          [,1] [,2] [,3] [,4] [,5] [,6]
## [1,] 0.0170079011 0.061609424 0.14727654 0.20054294 0.2840018 0.3540798
## [2,] 0.0344387612 0.284876009 0.35532135 0.37367902 0.4211311 0.5487794
## [3,] 0.2541255257 0.335218325 0.48145216 0.54288280 0.5710001 0.5770378
## [4,] 0.1073091202 0.117977130 0.13424199 0.25331902 0.5128014 0.5350316
## [5,] 0.2732552418 0.357400189 0.38876221 0.40715360 0.5381468 0.5406786
## [6,] 0.0132819042 0.090745371 0.24430075 0.48614898 0.5152457 0.5976601
## [7,] 0.0908959855 0.131626568 0.22145195 0.34794747 0.4608159 0.5554957
## [8,] 0.0056423799 0.167463865 0.22006326 0.33485213 0.7640813 0.7714948
## [9,] 0.2093792928 0.282170991 0.33862377 0.48519842 0.5354299 0.6294168
```

##	[10,]	0.0317132040	0.031788581	0.07838116	0.11922118	0.1538674	0.2278493
##	[11,]	0.0042672392	0.028374213	0.15082529	0.17177714	0.1801337	0.3140470
##	[12,]	0.0520230699	0.194530177	0.20438361	0.22693967	0.2844474	0.3871236
##	[13,]	0.1117601057	0.155974595	0.23817999	0.29283673	0.3569472	0.5809305
##	[14,]	0.0505923778	0.075758994	0.11478587	0.19961941	0.2558784	0.7807398
##	[15,]	0.0710949900	0.383738205	0.54741151	0.59399330	0.6583775	0.6904205
##	[16,]	0.0379184696	0.132899838	0.15325065	0.28496926	0.5463376	0.6536839
##	[17,]	0.0404609409	0.045015601	0.07839758	0.32345115	0.4575361	0.7554918
##	[18,]	0.0051084850	0.072854733	0.08003769	0.09800068	0.4169248	0.6168035
##	[19,]	0.0048874374	0.173998111	0.24273299	0.25226414	0.4552600	0.5111729
##	[20,]	0.0883712063	0.108593236	0.24935597	0.39835168	0.4498747	0.5489804
##	[21,]	0.2487929298	0.340778902	0.34894604	0.43445422	0.5379832	0.6194482
##	[22,]	0.1513924168	0.168998585	0.23737288	0.28017151	0.4525200	0.5542834
##	[23,]	0.0360772412	0.204372876	0.23544398	0.23920695	0.2819144	0.3217469
##	[24,]	0.2533900065	0.358394808	0.40174211	0.51072452	0.5823269	0.7426223
##	[25,]	0.0709323795	0.099951109	0.15461324	0.17742404	0.1973173	0.3105650
##	[26,]	0.0028992682	0.026214233	0.03586513	0.20597924	0.2183748	0.2265993
##	[27,]	0.0719839728	0.220024403	0.33162395	0.41182658	0.4541295	0.5099575
##	[28,]	0.2848204270	0.366973210	0.39802370	0.43417094	0.5520645	0.5818326
##	[29,]	0.1853831999	0.227009915	0.30569644	0.36261457	0.5108973	0.6042071
##	[30,]	0.0664060311	0.221774129	0.34629353	0.58495263	0.6784895	0.7112717
##	[31,]	0.0282371219	0.250235348	0.25817186	0.25846953	0.3797742	0.4542303
##	[32,]	0.2166616134	0.259392053	0.66280369	0.66870470	0.6784545	0.6879428
##	[33,]	0.0240876088	0.119236229	0.15832773	0.17742281	0.2895454	0.4208117
##	[34,]	0.0028211880	0.073101765	0.09671919	0.24637413	0.4725192	0.6596227
##	[35,]	0.1465037472	0.272334988	0.36080378	0.40084343	0.4555817	0.7546650
##	[36,]	0.2072158461	0.315793792	0.33649508	0.41214330	0.5568857	0.5768047
##	[37,]	0.0572949427	0.076359446	0.09002636	0.16721370	0.4588504	0.4951725
##	[38,]	0.0663247637	0.205245066	0.42988233	0.54228472	0.5796385	0.6943087
##	[39,]	0.0757229831	0.138885726	0.23811422	0.43529900	0.4850666	0.8698776
##	[40,]	0.0736379549	0.109096012	0.15724358	0.49232442	0.5055311	0.6939464
##	[41,]	0.0836981393	0.245056537	0.31668932	0.41589917	0.5476818	0.7695038
##	[42,]	0.1235427114	0.134513533	0.22246864	0.27561029	0.3294700	0.3369114
##	[43,]	0.0668859112	0.172911806	0.23873700	0.50721997	0.6080520	0.6290997
##	[44,]	0.0362904740	0.284868514	0.29048960	0.43910083	0.4899626	0.5653669
##	[45,]	0.0448116304	0.351680791	0.47406010	0.48109012	0.5087835	0.5321378
##	[46,]	0.0653892939	0.259008332	0.26591096	0.27954889	0.3330592	0.3847562
##	[47,]	0.0392489601	0.057422890	0.12841475	0.40131246	0.5398134	0.8174918
##	[48,]	0.1267656311	0.149819063	0.15238088	0.25163546	0.4927848	0.6443310
##	[49,]	0.2457893330	0.322147847	0.45417475	0.45568889	0.5684189	0.6632449
##	[50,]	0.1893787137	0.215222623	0.22378404	0.35166672	0.3692244	0.4639316
##	[51,]	0.0351125086	0.080236230	0.17759839	0.34401174	0.4130646	0.6123525
##	[52,]	0.1155603256	0.140778741	0.38247565	0.38900009	0.5689443	0.6244930
##	[53,]	0.0236329434	0.038597083	0.05078592	0.10698947	0.1491589	0.1569524
##	[54,]	0.0170216607	0.019787824	0.45806532	0.46607207	0.4992353	0.6385197
##	[55,]	0.0243759397	0.106630008	0.16423091	0.21782245	0.2513577	0.4248605
##	[56,]	0.0361960020	0.066845112	0.33987375	0.36562344	0.4542587	0.5087410
##	[57,]	0.2236258322	0.260703865	0.28936654	0.34015628	0.4482176	0.6090919
##	[58,]	0.1027294151	0.246718649	0.26731629	0.27640259	0.3374988	0.3423055
##	[59,]	0.1104736200	0.121212002	0.24789418	0.37032448	0.4634514	0.4758020
##	[60,]	0.1036454972	0.234915792	0.31903838	0.36614610	0.3758966	0.3905181
##	[61,]	0.0210118429	0.077816255	0.16830335	0.28114868	0.2872083	0.2909836
##	[62,]	0.0341706455	0.080822553	0.16528370	0.18926555	0.2646206	0.3180230
##	[63,]	0.0803241150	0.109945633	0.40812315	0.49140688	0.5109418	0.6168964

##	[64,]	0.0121429462	0.034669391	0.21129291	0.21264505	0.2329801	0.4198509
##	[65,]	0.0627861295	0.355839621	0.36934676	0.43177689	0.4385707	0.8277526
##	[66,]	0.0585474407	0.146671165	0.24387579	0.28297134	0.3977061	0.4555874
##	[67,]	0.0081477030	0.181809379	0.49002842	0.50246327	0.7224569	0.7394956
##	[68,]	0.0270565236	0.088853414	0.23661593	0.40724470	0.4211061	0.6108871
##	[69,]	0.0081483482	0.040871849	0.07984441	0.32533187	0.5973754	0.6169701
##	[70,]	0.0587735532	0.076765792	0.07791245	0.24434044	0.3280352	0.5160937
##	[71,]	0.1023351324	0.187065096	0.42144608	0.50919707	0.5148996	0.5511461
##	[72,]	0.0011953502	0.077013508	0.26526411	0.34909035	0.5032016	0.5280435
##	[73,]	0.1618808699	0.403221269	0.52327842	0.54761878	0.6080334	0.6766351
##	[74,]	0.1685923673	0.223767723	0.29635777	0.32471556	0.3967623	0.5451660
##	[75,]	0.0877224093	0.257218853	0.43563187	0.46828359	0.4695372	0.4897423
##	[76,]	0.0113401930	0.060331176	0.07574408	0.21508323	0.2394963	0.2561120
##	[77,]	0.2481487393	0.258602297	0.32936538	0.33879632	0.3566041	0.5344833
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## [993,] 0.4771655 0.6700508 0.6893179 0.8250362
## [994,] 0.7840174 0.8621636 0.8698923 0.8882137
## [995,] 0.7871068 0.8019947 0.8877577 0.9664196
## [996,] 0.5866091 0.6643854 0.6667872 0.7674587
## [997,] 0.5397895 0.5432937 0.5436453 0.9132807
## [998,] 0.8044087 0.8123301 0.8738860 0.9428503
## [999,] 0.7694266 0.7698877 0.8549014 0.8762162
## [1000,] 0.7941422 0.8965754 0.9127048 0.9761594
```

```
# second smallest values of each row
```

```
x.2 <- M.1[,2]
```

```
x.2
```

```
## [1] 0.061609424 0.284876009 0.335218325 0.117977130 0.357400189 0.090745371
## [7] 0.131626568 0.167463865 0.282170991 0.031788581 0.028374213 0.194530177
```

##	[13]	0.155974595	0.075758994	0.383738205	0.132899838	0.045015601	0.072854733
##	[19]	0.173998111	0.108593236	0.340778902	0.168998585	0.204372876	0.358394808
##	[25]	0.099951109	0.026214233	0.220024403	0.366973210	0.227009915	0.221774129
##	[31]	0.250235348	0.259392053	0.119236229	0.073101765	0.272334988	0.315793792
##	[37]	0.076359446	0.205245066	0.138885726	0.109096012	0.245056537	0.134513533
##	[43]	0.172911806	0.284868514	0.351680791	0.259008332	0.057422890	0.149819063
##	[49]	0.322147847	0.215222623	0.080236230	0.140778741	0.038597083	0.019787824
##	[55]	0.106630008	0.066845112	0.260703865	0.246718649	0.121212002	0.234915792
##	[61]	0.077816255	0.080822553	0.109945633	0.034669391	0.355839621	0.146671165
##	[67]	0.181809379	0.088853414	0.040871849	0.076765792	0.187065096	0.077013508
##	[73]	0.403221269	0.223767723	0.257218853	0.060331176	0.258602297	0.036619544
##	[79]	0.175018488	0.050341732	0.203874516	0.423491997	0.219794163	0.186499061
##	[85]	0.370726246	0.251764228	0.283529730	0.156215733	0.118293810	0.226377301
##	[91]	0.098321768	0.065801964	0.085951917	0.013109717	0.075510727	0.361883365
##	[97]	0.178165076	0.019865358	0.102147887	0.161596126	0.175646111	0.140771796
##	[103]	0.272780316	0.212922993	0.009366475	0.085697400	0.089914952	0.148155870
##	[109]	0.072987886	0.141529372	0.296236181	0.284499723	0.034419505	0.152984692
##	[115]	0.097248834	0.008526021	0.157602083	0.277052550	0.012552510	0.228276154
##	[121]	0.325261015	0.225636233	0.376408368	0.052702025	0.028470038	0.285853999
##	[127]	0.228665867	0.288920138	0.068274991	0.182152950	0.041934537	0.261202744
##	[133]	0.163151563	0.029277307	0.276123640	0.352220267	0.307485261	0.042757393
##	[139]	0.133728752	0.239350285	0.188161293	0.254555075	0.084935424	0.186026754
##	[145]	0.061119996	0.068742439	0.102115365	0.178492640	0.102829279	0.104079346
##	[151]	0.093649853	0.144428080	0.143676783	0.409256897	0.171145767	0.132664275
##	[157]	0.156449617	0.187689346	0.387977738	0.054493907	0.154373487	0.174120710
##	[163]	0.082235445	0.230066100	0.190409639	0.239637228	0.349236914	0.111421905
##	[169]	0.067296150	0.437049825	0.213458849	0.049255880	0.207404345	0.229959039
##	[175]	0.246394115	0.167834845	0.025891337	0.230055250	0.296785496	0.369364126
##	[181]	0.249083919	0.077821894	0.201155898	0.255641343	0.187911816	0.044367035
##	[187]	0.036116867	0.106530145	0.548177516	0.283879898	0.377029080	0.364361932
##	[193]	0.189248029	0.202912412	0.180890348	0.261379010	0.069070202	0.194542352
##	[199]	0.140566862	0.295266494	0.064712493	0.355703650	0.177401563	0.111299667
##	[205]	0.066297009	0.082294405	0.173349934	0.155160398	0.021184093	0.173205890
##	[211]	0.107906996	0.247532061	0.084921059	0.198593729	0.095049976	0.291031916
##	[217]	0.106243965	0.081624413	0.132591910	0.139561149	0.035948292	0.076451718
##	[223]	0.099744735	0.152283743	0.102820010	0.177998769	0.285948883	0.098199720
##	[229]	0.343203136	0.413305871	0.331940473	0.080246371	0.209279713	0.322619700
##	[235]	0.059149935	0.098321686	0.136255458	0.279481675	0.260042868	0.152667565
##	[241]	0.041392598	0.118364717	0.172647431	0.095315151	0.207339640	0.123852212
##	[247]	0.033453158	0.263550981	0.401709436	0.251715781	0.042142009	0.283284486
##	[253]	0.156366555	0.027496246	0.116375717	0.165352205	0.064376037	0.005788442
##	[259]	0.289269895	0.018195662	0.050523642	0.322919441	0.118785095	0.049183830
##	[265]	0.011742868	0.191251891	0.336995832	0.160794631	0.355648534	0.207135493
##	[271]	0.220770887	0.012836308	0.200598640	0.229866123	0.097371553	0.052268423
##	[277]	0.063766200	0.123112412	0.379413213	0.201222010	0.380625841	0.261175242
##	[283]	0.124168200	0.158678179	0.141059438	0.209032755	0.077378807	0.257467290
##	[289]	0.050977725	0.112693231	0.222873897	0.564176380	0.241871211	0.182594206
##	[295]	0.207682233	0.120087367	0.160300338	0.107185220	0.187288676	0.570033088
##	[301]	0.217831556	0.033014413	0.055899523	0.079924580	0.131966556	0.219971669
##	[307]	0.346423432	0.151568263	0.153661910	0.285330581	0.228585131	0.131660763
##	[313]	0.009857917	0.119079218	0.090219854	0.181170874	0.134271825	0.070688049
##	[319]	0.068940629	0.090797903	0.038751502	0.046113234	0.220477794	0.050908403
##	[325]	0.264677956	0.359491006	0.144622108	0.370525331	0.152961833	0.574558311
##	[331]	0.033287856	0.092509381	0.099763794	0.141507693	0.432889736	0.177000096

[337] 0.207688440 0.494502024 0.295927915 0.063312479 0.183621983 0.259546158
 ## [343] 0.152462915 0.164245682 0.450814908 0.390575896 0.320035003 0.090213704
 ## [349] 0.255079050 0.104024431 0.168894380 0.320466553 0.091138610 0.181874628
 ## [355] 0.067404743 0.249126208 0.106613972 0.054539655 0.199142303 0.129573060
 ## [361] 0.089037284 0.130751209 0.263422042 0.300493194 0.110402759 0.258463774
 ## [367] 0.157595142 0.074514975 0.151413594 0.136991804 0.131281727 0.041824817
 ## [373] 0.051309217 0.168274397 0.289797398 0.074397909 0.284621345 0.271286847
 ## [379] 0.202289626 0.057501056 0.103595298 0.600968129 0.196006852 0.126274642
 ## [385] 0.123573944 0.174017543 0.387805649 0.027734727 0.046900366 0.027187718
 ## [391] 0.018270930 0.301448873 0.506427261 0.097023585 0.066174826 0.205663136
 ## [397] 0.128149077 0.123878985 0.222705977 0.091445192 0.265813410 0.140876299
 ## [403] 0.128657653 0.153380945 0.135412243 0.209967003 0.282188267 0.202303132
 ## [409] 0.429601911 0.106167401 0.120768556 0.191270514 0.115548655 0.313704825
 ## [415] 0.138865773 0.053694005 0.185451959 0.038866585 0.243890297 0.030011677
 ## [421] 0.198293858 0.188632000 0.323390743 0.064195928 0.383629692 0.133983675
 ## [427] 0.088952074 0.120329412 0.050832701 0.374545260 0.198231223 0.028259974
 ## [433] 0.086793459 0.056240941 0.072208702 0.377908695 0.334189285 0.162273674
 ## [439] 0.328781780 0.496440161 0.239070263 0.122022249 0.129109287 0.061127951
 ## [445] 0.236220999 0.209322826 0.293246638 0.246009253 0.438321433 0.192165966
 ## [451] 0.104029369 0.123599376 0.186720415 0.136479732 0.039244042 0.030250543
 ## [457] 0.068710022 0.090560078 0.174504111 0.055379754 0.109745524 0.111308733
 ## [463] 0.036567337 0.188894553 0.162863294 0.046293979 0.131950644 0.334867247
 ## [469] 0.087940061 0.049882534 0.171487077 0.057908962 0.068927153 0.046445694
 ## [475] 0.086135833 0.160547793 0.183787841 0.067794490 0.135187423 0.104700660
 ## [481] 0.251966297 0.251235501 0.366745681 0.102720966 0.095879028 0.330213448
 ## [487] 0.077647318 0.202289816 0.485480662 0.125777412 0.124777175 0.529761809
 ## [493] 0.484062518 0.119479756 0.079918742 0.051509608 0.070160991 0.339283207
 ## [499] 0.113951277 0.072070498 0.066714149 0.247539758 0.311910334 0.373224894
 ## [505] 0.274403698 0.280473913 0.076370532 0.340870337 0.405973302 0.107584562
 ## [511] 0.006082598 0.178273742 0.303850163 0.176780154 0.208237443 0.056194862
 ## [517] 0.139022846 0.163245677 0.081369559 0.366268068 0.239049473 0.104512860
 ## [523] 0.308141776 0.315790087 0.199519189 0.114016148 0.015862073 0.056768513
 ## [529] 0.027755822 0.333610649 0.069730199 0.084880809 0.090317772 0.049479483
 ## [535] 0.358941921 0.065067437 0.117943447 0.254559968 0.232515225 0.279742562
 ## [541] 0.217431410 0.104652790 0.337746056 0.111786963 0.290173517 0.134025161
 ## [547] 0.117235640 0.042920831 0.231763274 0.162106824 0.075874967 0.196981138
 ## [553] 0.145670358 0.076959072 0.231745099 0.164756294 0.271073145 0.232967449
 ## [559] 0.127813229 0.085089764 0.288577761 0.015838218 0.155683852 0.209013989
 ## [565] 0.314893951 0.314168265 0.218499390 0.365101550 0.141016566 0.468843336
 ## [571] 0.314674407 0.036818970 0.043172329 0.056243818 0.174416814 0.451896371
 ## [577] 0.122671921 0.291007829 0.107359265 0.175206373 0.111477637 0.331929789
 ## [583] 0.168936401 0.061049603 0.153450242 0.373243761 0.175364340 0.138003347
 ## [589] 0.035949216 0.262405766 0.268942745 0.041017657 0.018193165 0.337955133
 ## [595] 0.329129653 0.376664158 0.290173398 0.248724160 0.090405711 0.168699684
 ## [601] 0.069458742 0.071240221 0.371038995 0.377998808 0.013173746 0.356232541
 ## [607] 0.017597033 0.050309023 0.130621741 0.143181366 0.103629632 0.403614088
 ## [613] 0.138351323 0.185593012 0.336524108 0.162278153 0.064423084 0.386880759
 ## [619] 0.094563929 0.202788350 0.137940163 0.116892941 0.239341634 0.088926021
 ## [625] 0.052150619 0.270209173 0.280016493 0.536669396 0.217940803 0.135456671
 ## [631] 0.010268549 0.514878331 0.042594744 0.302649111 0.082213427 0.200715304
 ## [637] 0.056348672 0.133114166 0.258470003 0.259914484 0.302508435 0.236143617
 ## [643] 0.218016276 0.088542651 0.218065007 0.123503282 0.354767087 0.025192193
 ## [649] 0.206764796 0.128366638 0.003516218 0.234714680 0.117799712 0.025546549
 ## [655] 0.135035213 0.233513254 0.426751776 0.027769605 0.235728077 0.062430157

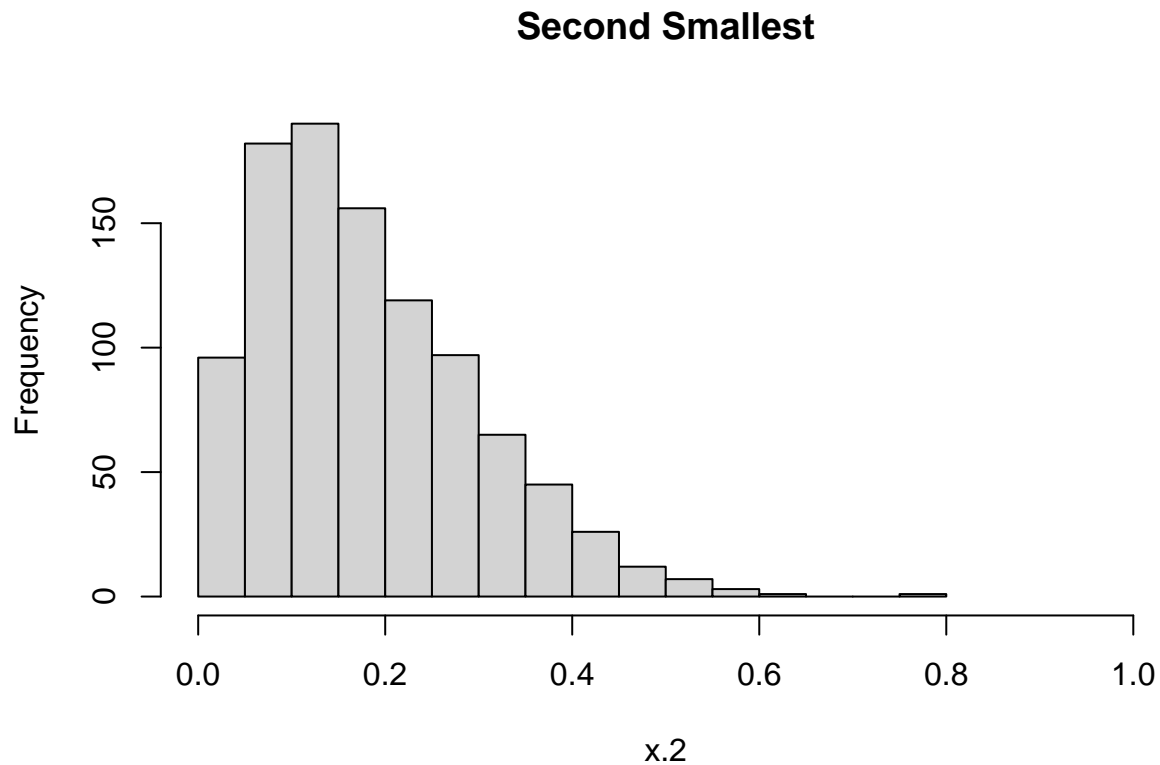
```

## [661] 0.278536374 0.253751796 0.293860214 0.128149378 0.067109976 0.300920752
## [667] 0.124929510 0.188444575 0.139465736 0.143078158 0.308047227 0.501952701
## [673] 0.194604596 0.149399920 0.123295781 0.445182652 0.239092200 0.093866454
## [679] 0.154339585 0.338603851 0.095122246 0.046528774 0.186083897 0.239084220
## [685] 0.465051821 0.111070907 0.071202345 0.081141417 0.166756350 0.219865275
## [691] 0.102181473 0.163013663 0.253598568 0.022668031 0.208459951 0.195654083
## [697] 0.268799803 0.269467698 0.152605408 0.311447183 0.072877357 0.211456225
## [703] 0.094344703 0.297417618 0.105562191 0.196244740 0.334934894 0.018505931
## [709] 0.098391772 0.156794907 0.099474260 0.154046742 0.101898520 0.190689533
## [715] 0.115792008 0.132017247 0.131011147 0.088308024 0.120048779 0.246284653
## [721] 0.334860898 0.309041247 0.101816672 0.316303235 0.059376145 0.176097968
## [727] 0.161737922 0.179992513 0.014892920 0.051562881 0.132414495 0.283779509
## [733] 0.163559866 0.103784537 0.305312758 0.114601608 0.069106708 0.290567800
## [739] 0.132961039 0.354204974 0.006459725 0.003304547 0.047979860 0.160547960
## [745] 0.290325600 0.259208594 0.021685626 0.083889605 0.216019648 0.084917732
## [751] 0.163320454 0.120212745 0.069494832 0.239879170 0.389861946 0.126905655
## [757] 0.214108393 0.254264225 0.175701861 0.221750567 0.106990375 0.158851962
## [763] 0.400004534 0.043793108 0.113761039 0.049620316 0.492609066 0.163300842
## [769] 0.121668434 0.341049790 0.149962643 0.403324390 0.136211386 0.237607023
## [775] 0.455575515 0.434856937 0.197969936 0.133555687 0.131674617 0.302385350
## [781] 0.114559705 0.236138895 0.055056964 0.187164645 0.071677877 0.126493622
## [787] 0.431123465 0.277810890 0.327387171 0.204957213 0.325495037 0.111350948
## [793] 0.072712372 0.140509183 0.130769005 0.130190585 0.327387342 0.280259828
## [799] 0.017349499 0.117589337 0.074419405 0.196436846 0.249395281 0.284091336
## [805] 0.168583859 0.055099573 0.113990663 0.071413339 0.211687837 0.075210877
## [811] 0.166285433 0.073479738 0.178157207 0.413061508 0.141462349 0.216348840
## [817] 0.193039025 0.055844880 0.070626296 0.204579910 0.299001173 0.099569243
## [823] 0.766329948 0.096861294 0.464907582 0.233544712 0.015129596 0.217531709
## [829] 0.448093526 0.107474350 0.149058597 0.190255427 0.115046704 0.150548422
## [835] 0.043699902 0.236690307 0.090323754 0.164582473 0.335506540 0.061969873
## [841] 0.075494010 0.187907136 0.376446147 0.281323126 0.227361978 0.149502076
## [847] 0.072920854 0.111148797 0.136306449 0.076831438 0.197876819 0.193242711
## [853] 0.432412920 0.328341856 0.201401843 0.391498799 0.036905746 0.177186662
## [859] 0.048610565 0.134841169 0.202297590 0.292823453 0.238477805 0.110538739
## [865] 0.075817130 0.088909803 0.275812621 0.138164391 0.340630787 0.085918879
## [871] 0.103389583 0.334765581 0.256160221 0.101620901 0.248682106 0.150870941
## [877] 0.148588431 0.294057350 0.162670300 0.121866470 0.135597521 0.147493625
## [883] 0.019199430 0.128787193 0.289226401 0.236158282 0.274956625 0.204031246
## [889] 0.352847454 0.102161068 0.254181929 0.368227571 0.154605060 0.198444478
## [895] 0.191268652 0.193618549 0.157509761 0.336253481 0.345069350 0.143619878
## [901] 0.148618585 0.170448688 0.113132544 0.124061871 0.151171787 0.177430625
## [907] 0.069649157 0.220334408 0.067627618 0.172143615 0.103250428 0.203711141
## [913] 0.120749428 0.253431505 0.170097689 0.182544295 0.239276083 0.085109209
## [919] 0.207538185 0.242746019 0.160246446 0.400790709 0.095747642 0.311245301
## [925] 0.144678464 0.168889827 0.025106606 0.447859600 0.154381476 0.377379094
## [931] 0.252317296 0.058622448 0.132818012 0.445363661 0.051941172 0.335136016
## [937] 0.332284449 0.222486521 0.164227151 0.150468136 0.287439984 0.252871818
## [943] 0.335560647 0.109029030 0.087896956 0.080569488 0.395831556 0.099099833
## [949] 0.064242088 0.097879041 0.058521757 0.112777991 0.226818922 0.044284578
## [955] 0.112941488 0.140646962 0.039876486 0.528278077 0.265165970 0.062122158
## [961] 0.079504441 0.270111576 0.111213281 0.300048607 0.239189232 0.409362429
## [967] 0.227025170 0.038935452 0.124733391 0.219660270 0.096901571 0.127142050
## [973] 0.100653077 0.227041789 0.033014418 0.083508158 0.193044016 0.074695295
## [979] 0.406425644 0.215842896 0.105868489 0.175651997 0.079441927 0.161178244

```

```
## [985] 0.080111372 0.112039124 0.187822166 0.170680982 0.160867940 0.191904359
## [991] 0.473273858 0.025030762 0.149301019 0.220851791 0.079004810 0.139455228
## [997] 0.018383573 0.039219217 0.299391138 0.432708991
```

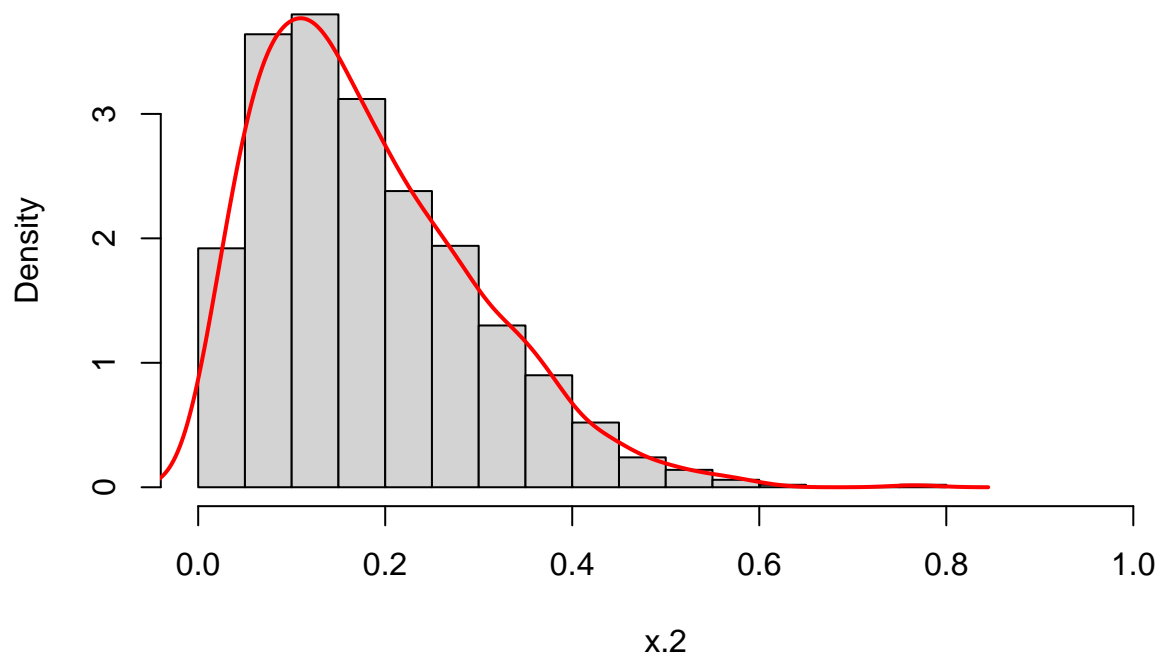
```
# histogram of second smallest values of each row
hist(x.2, xlim = c(0, 1), main = "Second Smallest")
```



practice 2: plot the density function together

```
hist(x.2, xlim = c(0, 1), freq = F, main = "Second Smallest")
lines(density(x.2), col = "red", lwd = 2)
```

Second Smallest



4. rownames(), colnames(), dummy coding of categorical variables

ex1

```
n <- 10
X <- matrix(round(rnorm(n * 4, 50, 10)), n, 4)

rownames(X) <- paste("S", 1:n, sep = "")
colnames(X) <- c("math", "engl", "science", "arts")

X
```

```
##      math engl science arts
## S1    53   65      57   44
## S2    60   51      43   56
## S3    28   65      49   49
## S4    42   45      53   62
## S5    49   50      42   44
## S6    63   45      41   21
## S7    49   47      62   38
## S8    41   64      43   63
## S9    50   33      45   60
## S10   58   54      42   65
```

indicator coding and frequency table: dummy coding of categorical variables

```
# get the gender information and specific answer from 1 to 3. n = 20
# random sampling of gender
```



```

n <- 20
gender <- sample(1:2, n, replace = T)

gender

## [1] 2 2 1 2 2 2 1 2 2 1 1 1 1 2 2 2 1 2 1
# random sampling of answer
answer <- sample(1:3, n, replace = T, prob = c(0.25, 0.5, 0.25))

answer

## [1] 3 3 1 3 2 3 1 1 1 2 2 1 2 3 2 1 3 2 2 2
# dummy coding: gender vector with length n -> n x 2 matrix
## for loop
gender.matrix <- matrix(0, n, 2)
for (i in 1:n) gender.matrix[i, gender[i]] <- 1

gender.matrix

##      [,1] [,2]
## [1,]    0    1
## [2,]    0    1
## [3,]    1    0
## [4,]    0    1
## [5,]    0    1
## [6,]    0    1
## [7,]    1    0
## [8,]    0    1
## [9,]    0    1
## [10,]   1    0
## [11,]   1    0
## [12,]   1    0
## [13,]   1    0
## [14,]   1    0
## [15,]   0    1
## [16,]   0    1
## [17,]   0    1
## [18,]   1    0
## [19,]   0    1
## [20,]   1    0

## indexing
gender.matrix <- matrix(0, n, 2)
gender.matrix[1:n + n * (gender - 1)] <- 1

gender.matrix

##      [,1] [,2]
## [1,]    0    1
## [2,]    0    1
## [3,]    1    0
## [4,]    0    1
## [5,]    0    1
## [6,]    0    1

```

```
## [7,] 1 0
## [8,] 0 1
## [9,] 0 1
## [10,] 1 0
## [11,] 1 0
## [12,] 1 0
## [13,] 1 0
## [14,] 1 0
## [15,] 0 1
## [16,] 0 1
## [17,] 0 1
## [18,] 1 0
## [19,] 0 1
## [20,] 1 0
```

```
## naming the columns and rows
```

```
colnames(gender.matrix) <- paste("gender", 1:2, sep = ".")
rownames(gender.matrix) <- paste("subject", 1:n, sep = ".")
```

```
head(gender.matrix, 10)
```

```
##           gender.1 gender.2
## subject.1         0         1
## subject.2         0         1
## subject.3         1         0
## subject.4         0         1
## subject.5         0         1
## subject.6         0         1
## subject.7         1         0
## subject.8         0         1
## subject.9         0         1
## subject.10        1         0
```

```
## frequency table
```

```
apply(gender.matrix, 2, sum)
```

```
## gender.1 gender.2
##          9       11
```

```
## dummy coding and frequency table of answer with apply() function
```

```
answer.matrix <- matrix(0, n, 3)
answer.matrix[1:n + n * (answer - 1)] <- 1
```

```
colnames(answer.matrix) <- paste("answer", 1:3, sep = ".")
apply(answer.matrix, 2, sum)
```

```
## answer.1 answer.2 answer.3
##          6         8         6
```

```
## cross-tabulation: matrix multiplication
```

```
cross.tab <- t(gender.matrix) %*% answer.matrix
```

```
cross.tab
```

```
##           answer.1 answer.2 answer.3
## gender.1         3         5         1
## gender.2         3         3         5
```

```
## cross-tabulation: table() fucntion  
table(gender, answer)
```

```
##      answer  
## gender 1 2 3  
##      1 3 5 1  
##      2 3 3 5
```

```
### class.ind() function of nnet: character vector -> dummy coding vector
```