chapter 4(4.1 - 4.6)

Chapter 4 The tidyverse

Up to now we have been manipulating vectors by reordering and subsetting them through indexing. However, once we start more advanced analyses, the preferred unit for data storage is not the vector but the data frame. In this chapter we learn to work directly with data frames, which greatly facilitate the organization of information. We will be using data frames for the majority of this book. We will focus on a specific data format referred to as *tidy* and on specific collection of packages that are particularly helpful for working with *tidy data* referred to as the *tidyverse.*

We can load all the tidyverse packages at once by installing and loading the **tidyverse** package:

```
library(tidyverse)
```

```
## -- Attaching packages --------------------------------------- tidyverse 1.3.1 --
```

```
## v ggplot2 3.3.5     v purrr   0.3.4
## v tibble  3.1.4     v dplyr   1.0.7
## v tidyr   1.1.3     v stringr 1.4.0
## v readr   2.0.1     v forcats 0.5.1
```

```
## -- Conflicts ------------------------------------------ tidyverse_conflicts() --
## x dplyr::filter() masks stats::filter()
## x dplyr::lag()    masks stats::lag()
```

We will learn how to implement the tidyverse approach throughout the book, but before delving into the details, in this chapter we introduce some of the most widely used tidyverse functionality, starting with the **dplyr** package for manipulating data frames and the **purrr** package for working with functions. Note that the tidyverse also includes a graphing package, **ggplot2**, which we introduce later in Chapter 7 in the Data Visualization part of the book; the **readr** package discussed in Chapter 5; and many others. In this chapter, we first introduce the concept of *tidy data* and then demonstrate how we use the tidyverse to work with data frames in this format.

4.1 Tidy data

We say that a data table is in *tidy* format if each row represents one observation and columns represent the different variables available for each of these observations. The `murders` dataset is an example of a tidy data frame.

```
#>         state abb region population total
#> 1     Alabama  AL  South    4779736   135
#> 2      Alaska  AK   West     710231    19
#> 3     Arizona  AZ   West    6392017   232
#> 4    Arkansas  AR  South    2915918    93
#> 5  California  CA   West   37253956  1257
#> 6    Colorado  CO   West    5029196    65
```

Each row represent a state with each of the five columns providing a different variable related to these states: name, abbreviation, region, population, and total murders.

To see how the same information can be provided in different formats, consider the following example:

```
#>        country year fertility
#> 1      Germany 1960      2.41
#> 2 South Korea 1960      6.16
#> 3      Germany 1961      2.44
#> 4 South Korea 1961      5.99
#> 5      Germany 1962      2.47
#> 6 South Korea 1962      5.79
```

This tidy dataset provides fertility rates for two countries across the years. This is a tidy dataset because each row presents one observation with the three variables being country, year, and fertility rate. However, this dataset originally came in another format and was reshaped for the **dslabs** package. Originally, the data was in the following format:

```
#>        country 1960 1961 1962
#> 1      Germany 2.41 2.44 2.47
#> 2 South Korea 6.16 5.99 5.79
```

The same information is provided, but there are two important differences in the format: 1) each row includes several observations and 2) one of the variables, year, is stored in the header. For the tidyverse packages to be optimally used, data need to be reshaped into tidy format, which you will learn to do in the Data Wrangling part of the book. Until then, we will use example datasets that are already in tidy format.

Although not immediately obvious, as you go through the book you will start to appreciate the advantages of working in a framework in which functions use tidy formats for both inputs and outputs. You will see how this permits the data analyst to focus on more important aspects of the analysis rather than the format of the data.

4.2 Exercises

1. Examine the built-in dataset `co2`. Which of the following is true:

a. `co2` is tidy data: it has one year for each row.
b. `co2` is not tidy: we need at least one column with a character vector.
c. `co2` is not tidy: it is a matrix instead of a data frame.
d. `co2` is not tidy: to be tidy we would have to wrangle it to have three columns (year, month and value), then each `co2` observation would have a row.

```
co2
```

```
##         Jan    Feb    Mar    Apr    May    Jun    Jul    Aug    Sep    Oct
## 1959 315.42 316.31 316.50 317.56 318.13 318.00 316.39 314.65 313.68 313.18
## 1960 316.27 316.81 317.42 318.87 319.87 319.43 318.01 315.74 314.00 313.68
## 1961 316.73 317.54 318.38 319.31 320.42 319.61 318.42 316.63 314.83 315.16
## 1962 317.78 318.40 319.53 320.42 320.85 320.45 319.45 317.25 316.11 315.27
## 1963 318.58 318.92 319.70 321.22 322.08 321.31 319.58 317.61 316.05 315.83
## 1964 319.41 320.07 320.74 321.40 322.06 321.73 320.27 318.54 316.54 316.71
## 1965 319.27 320.28 320.73 321.97 322.00 321.71 321.05 318.71 317.66 317.14
## 1966 320.46 321.43 322.23 323.54 323.91 323.59 322.24 320.20 318.48 317.94
```

```
## 1967 322.17 322.34 322.88 324.25 324.83 323.93 322.38 320.76 319.10 319.24
## 1968 322.40 322.99 323.73 324.86 325.40 325.20 323.98 321.95 320.18 320.09
## 1969 323.83 324.26 325.47 326.50 327.21 326.54 325.72 323.50 322.22 321.62
## 1970 324.89 325.82 326.77 327.97 327.91 327.50 326.18 324.53 322.93 322.90
## 1971 326.01 326.51 327.01 327.62 328.76 328.40 327.20 325.27 323.20 323.40
## 1972 326.60 327.47 327.58 329.56 329.90 328.92 327.88 326.16 324.68 325.04
## 1973 328.37 329.40 330.14 331.33 332.31 331.90 330.70 329.15 327.35 327.02
## 1974 329.18 330.55 331.32 332.48 332.92 332.08 331.01 329.23 327.27 327.21
## 1975 330.23 331.25 331.87 333.14 333.80 333.43 331.73 329.90 328.40 328.17
## 1976 331.58 332.39 333.33 334.41 334.71 334.17 332.89 330.77 329.14 328.78
## 1977 332.75 333.24 334.53 335.90 336.57 336.10 334.76 332.59 331.42 330.98
## 1978 334.80 335.22 336.47 337.59 337.84 337.72 336.37 334.51 332.60 332.38
## 1979 336.05 336.59 337.79 338.71 339.30 339.12 337.56 335.92 333.75 333.70
## 1980 337.84 338.19 339.91 340.60 341.29 341.00 339.39 337.43 335.72 335.84
## 1981 339.06 340.30 341.21 342.33 342.74 342.08 340.32 338.26 336.52 336.68
## 1982 340.57 341.44 342.53 343.39 343.96 343.18 341.88 339.65 337.81 337.69
## 1983 341.20 342.35 342.93 344.77 345.58 345.14 343.81 342.21 339.69 339.82
## 1984 343.52 344.33 345.11 346.88 347.25 346.62 345.22 343.11 340.90 341.18
## 1985 344.79 345.82 347.25 348.17 348.74 348.07 346.38 344.51 342.92 342.62
## 1986 346.11 346.78 347.68 349.37 350.03 349.37 347.76 345.73 344.68 343.99
## 1987 347.84 348.29 349.23 350.80 351.66 351.07 349.33 347.92 346.27 346.18
## 1988 350.25 351.54 352.05 353.41 354.04 353.62 352.22 350.27 348.55 348.72
## 1989 352.60 352.92 353.53 355.26 355.52 354.97 353.75 351.52 349.64 349.83
## 1990 353.50 354.55 355.23 356.04 357.00 356.07 354.67 352.76 350.82 351.04
## 1991 354.59 355.63 357.03 358.48 359.22 358.12 356.06 353.92 352.05 352.11
## 1992 355.88 356.63 357.72 359.07 359.58 359.17 356.94 354.92 352.94 353.23
## 1993 356.63 357.10 358.32 359.41 360.23 359.55 357.53 355.48 353.67 353.95
## 1994 358.34 358.89 359.95 361.25 361.67 360.94 359.55 357.49 355.84 356.00
## 1995 359.98 361.03 361.66 363.48 363.82 363.30 361.94 359.50 358.11 357.80
## 1996 362.09 363.29 364.06 364.76 365.45 365.01 363.70 361.54 359.51 359.65
## 1997 363.23 364.06 364.61 366.40 366.84 365.68 364.52 362.57 360.24 360.83
##          Nov    Dec
## 1959 314.66 315.43
## 1960 314.84 316.03
## 1961 315.94 316.85
## 1962 316.53 317.53
## 1963 316.91 318.20
## 1964 317.53 318.55
## 1965 318.70 319.25
## 1966 319.63 320.87
## 1967 320.56 321.80
## 1968 321.16 322.74
## 1969 322.69 323.95
## 1970 323.85 324.96
## 1971 324.63 325.85
## 1972 326.34 327.39
## 1973 327.99 328.48
## 1974 328.29 329.41
## 1975 329.32 330.59
## 1976 330.14 331.52
## 1977 332.24 333.68
## 1978 333.75 334.78
## 1979 335.12 336.56
## 1980 336.93 338.04
```

```
## 1981 338.19 339.44
## 1982 339.09 340.32
## 1983 340.98 342.82
## 1984 342.80 344.04
## 1985 344.06 345.38
## 1986 345.48 346.72
## 1987 347.64 348.78
## 1988 349.91 351.18
## 1989 351.14 352.37
## 1990 352.69 354.07
## 1991 353.64 354.89
## 1992 354.09 355.33
## 1993 355.30 356.78
## 1994 357.59 359.05
## 1995 359.61 360.74
## 1996 360.80 362.38
## 1997 362.49 364.34
```

d

2. Examine the built-in dataset `ChickWeight`. Which of the following is true:

a. `ChickWeight` is not tidy: each chick has more than one row.
b. `ChickWeight` is tidy: each observation (a weight) is represented by one row. The chick from which this measurement came is one of the variables.
c. `ChickWeight` is not tidy: we are missing the year column.
d. `ChickWeight` is tidy: it is stored in a data frame.

ChickWeight

```
##      weight Time Chick Diet
## 1       42    0     1    1
## 2       51    2     1    1
## 3       59    4     1    1
## 4       64    6     1    1
## 5       76    8     1    1
## 6       93   10     1    1
## 7      106   12     1    1
## 8      125   14     1    1
## 9      149   16     1    1
## 10     171   18     1    1
## 11     199   20     1    1
## 12     205   21     1    1
## 13      40    0     2    1
## 14      49    2     2    1
## 15      58    4     2    1
## 16      72    6     2    1
## 17      84    8     2    1
## 18     103   10     2    1
## 19     122   12     2    1
## 20     138   14     2    1
## 21     162   16     2    1
## 22     187   18     2    1
```

```
## 23        209    20     2    1
## 24        215    21     2    1
## 25         43     0     3    1
## 26         39     2     3    1
## 27         55     4     3    1
## 28         67     6     3    1
## 29         84     8     3    1
## 30         99    10     3    1
## 31        115    12     3    1
## 32        138    14     3    1
## 33        163    16     3    1
## 34        187    18     3    1
## 35        198    20     3    1
## 36        202    21     3    1
## 37         42     0     4    1
## 38         49     2     4    1
## 39         56     4     4    1
## 40         67     6     4    1
## 41         74     8     4    1
## 42         87    10     4    1
## 43        102    12     4    1
## 44        108    14     4    1
## 45        136    16     4    1
## 46        154    18     4    1
## 47        160    20     4    1
## 48        157    21     4    1
## 49         41     0     5    1
## 50         42     2     5    1
## 51         48     4     5    1
## 52         60     6     5    1
## 53         79     8     5    1
## 54        106    10     5    1
## 55        141    12     5    1
## 56        164    14     5    1
## 57        197    16     5    1
## 58        199    18     5    1
## 59        220    20     5    1
## 60        223    21     5    1
## 61         41     0     6    1
## 62         49     2     6    1
## 63         59     4     6    1
## 64         74     6     6    1
## 65         97     8     6    1
## 66        124    10     6    1
## 67        141    12     6    1
## 68        148    14     6    1
## 69        155    16     6    1
## 70        160    18     6    1
## 71        160    20     6    1
## 72        157    21     6    1
## 73         41     0     7    1
## 74         49     2     7    1
## 75         57     4     7    1
## 76         71     6     7    1
```

```
## 77       89    8     7    1
## 78      112   10     7    1
## 79      146   12     7    1
## 80      174   14     7    1
## 81      218   16     7    1
## 82      250   18     7    1
## 83      288   20     7    1
## 84      305   21     7    1
## 85       42    0     8    1
## 86       50    2     8    1
## 87       61    4     8    1
## 88       71    6     8    1
## 89       84    8     8    1
## 90       93   10     8    1
## 91      110   12     8    1
## 92      116   14     8    1
## 93      126   16     8    1
## 94      134   18     8    1
## 95      125   20     8    1
## 96       42    0     9    1
## 97       51    2     9    1
## 98       59    4     9    1
## 99       68    6     9    1
## 100      85    8     9    1
## 101      96   10     9    1
## 102      90   12     9    1
## 103      92   14     9    1
## 104      93   16     9    1
## 105     100   18     9    1
## 106     100   20     9    1
## 107      98   21     9    1
## 108      41    0    10    1
## 109      44    2    10    1
## 110      52    4    10    1
## 111      63    6    10    1
## 112      74    8    10    1
## 113      81   10    10    1
## 114      89   12    10    1
## 115      96   14    10    1
## 116     101   16    10    1
## 117     112   18    10    1
## 118     120   20    10    1
## 119     124   21    10    1
## 120      43    0    11    1
## 121      51    2    11    1
## 122      63    4    11    1
## 123      84    6    11    1
## 124     112    8    11    1
## 125     139   10    11    1
## 126     168   12    11    1
## 127     177   14    11    1
## 128     182   16    11    1
## 129     184   18    11    1
## 130     181   20    11    1
```

```
## 131     175     21     11     1
## 132      41      0     12     1
## 133      49      2     12     1
## 134      56      4     12     1
## 135      62      6     12     1
## 136      72      8     12     1
## 137      88     10     12     1
## 138     119     12     12     1
## 139     135     14     12     1
## 140     162     16     12     1
## 141     185     18     12     1
## 142     195     20     12     1
## 143     205     21     12     1
## 144      41      0     13     1
## 145      48      2     13     1
## 146      53      4     13     1
## 147      60      6     13     1
## 148      65      8     13     1
## 149      67     10     13     1
## 150      71     12     13     1
## 151      70     14     13     1
## 152      71     16     13     1
## 153      81     18     13     1
## 154      91     20     13     1
## 155      96     21     13     1
## 156      41      0     14     1
## 157      49      2     14     1
## 158      62      4     14     1
## 159      79      6     14     1
## 160     101      8     14     1
## 161     128     10     14     1
## 162     164     12     14     1
## 163     192     14     14     1
## 164     227     16     14     1
## 165     248     18     14     1
## 166     259     20     14     1
## 167     266     21     14     1
## 168      41      0     15     1
## 169      49      2     15     1
## 170      56      4     15     1
## 171      64      6     15     1
## 172      68      8     15     1
## 173      68     10     15     1
## 174      67     12     15     1
## 175      68     14     15     1
## 176      41      0     16     1
## 177      45      2     16     1
## 178      49      4     16     1
## 179      51      6     16     1
## 180      57      8     16     1
## 181      51     10     16     1
## 182      54     12     16     1
## 183      42      0     17     1
## 184      51      2     17     1
```

```
## 185      61    4    17    1
## 186      72    6    17    1
## 187      83    8    17    1
## 188      89   10    17    1
## 189      98   12    17    1
## 190     103   14    17    1
## 191     113   16    17    1
## 192     123   18    17    1
## 193     133   20    17    1
## 194     142   21    17    1
## 195      39    0    18    1
## 196      35    2    18    1
## 197      43    0    19    1
## 198      48    2    19    1
## 199      55    4    19    1
## 200      62    6    19    1
## 201      65    8    19    1
## 202      71   10    19    1
## 203      82   12    19    1
## 204      88   14    19    1
## 205     106   16    19    1
## 206     120   18    19    1
## 207     144   20    19    1
## 208     157   21    19    1
## 209      41    0    20    1
## 210      47    2    20    1
## 211      54    4    20    1
## 212      58    6    20    1
## 213      65    8    20    1
## 214      73   10    20    1
## 215      77   12    20    1
## 216      89   14    20    1
## 217      98   16    20    1
## 218     107   18    20    1
## 219     115   20    20    1
## 220     117   21    20    1
## 221      40    0    21    2
## 222      50    2    21    2
## 223      62    4    21    2
## 224      86    6    21    2
## 225     125    8    21    2
## 226     163   10    21    2
## 227     217   12    21    2
## 228     240   14    21    2
## 229     275   16    21    2
## 230     307   18    21    2
## 231     318   20    21    2
## 232     331   21    21    2
## 233      41    0    22    2
## 234      55    2    22    2
## 235      64    4    22    2
## 236      77    6    22    2
## 237      90    8    22    2
## 238      95   10    22    2
```

```
## 239   108  12  22  2
## 240   111  14  22  2
## 241   131  16  22  2
## 242   148  18  22  2
## 243   164  20  22  2
## 244   167  21  22  2
## 245    43   0  23  2
## 246    52   2  23  2
## 247    61   4  23  2
## 248    73   6  23  2
## 249    90   8  23  2
## 250   103  10  23  2
## 251   127  12  23  2
## 252   135  14  23  2
## 253   145  16  23  2
## 254   163  18  23  2
## 255   170  20  23  2
## 256   175  21  23  2
## 257    42   0  24  2
## 258    52   2  24  2
## 259    58   4  24  2
## 260    74   6  24  2
## 261    66   8  24  2
## 262    68  10  24  2
## 263    70  12  24  2
## 264    71  14  24  2
## 265    72  16  24  2
## 266    72  18  24  2
## 267    76  20  24  2
## 268    74  21  24  2
## 269    40   0  25  2
## 270    49   2  25  2
## 271    62   4  25  2
## 272    78   6  25  2
## 273   102   8  25  2
## 274   124  10  25  2
## 275   146  12  25  2
## 276   164  14  25  2
## 277   197  16  25  2
## 278   231  18  25  2
## 279   259  20  25  2
## 280   265  21  25  2
## 281    42   0  26  2
## 282    48   2  26  2
## 283    57   4  26  2
## 284    74   6  26  2
## 285    93   8  26  2
## 286   114  10  26  2
## 287   136  12  26  2
## 288   147  14  26  2
## 289   169  16  26  2
## 290   205  18  26  2
## 291   236  20  26  2
## 292   251  21  26  2
```

```
## 293     39    0   27   2
## 294     46    2   27   2
## 295     58    4   27   2
## 296     73    6   27   2
## 297     87    8   27   2
## 298    100   10   27   2
## 299    115   12   27   2
## 300    123   14   27   2
## 301    144   16   27   2
## 302    163   18   27   2
## 303    185   20   27   2
## 304    192   21   27   2
## 305     39    0   28   2
## 306     46    2   28   2
## 307     58    4   28   2
## 308     73    6   28   2
## 309     92    8   28   2
## 310    114   10   28   2
## 311    145   12   28   2
## 312    156   14   28   2
## 313    184   16   28   2
## 314    207   18   28   2
## 315    212   20   28   2
## 316    233   21   28   2
## 317     39    0   29   2
## 318     48    2   29   2
## 319     59    4   29   2
## 320     74    6   29   2
## 321     87    8   29   2
## 322    106   10   29   2
## 323    134   12   29   2
## 324    150   14   29   2
## 325    187   16   29   2
## 326    230   18   29   2
## 327    279   20   29   2
## 328    309   21   29   2
## 329     42    0   30   2
## 330     48    2   30   2
## 331     59    4   30   2
## 332     72    6   30   2
## 333     85    8   30   2
## 334     98   10   30   2
## 335    115   12   30   2
## 336    122   14   30   2
## 337    143   16   30   2
## 338    151   18   30   2
## 339    157   20   30   2
## 340    150   21   30   2
## 341     42    0   31   3
## 342     53    2   31   3
## 343     62    4   31   3
## 344     73    6   31   3
## 345     85    8   31   3
## 346    102   10   31   3
```

```
## 347    123   12   31   3
## 348    138   14   31   3
## 349    170   16   31   3
## 350    204   18   31   3
## 351    235   20   31   3
## 352    256   21   31   3
## 353     41    0   32   3
## 354     49    2   32   3
## 355     65    4   32   3
## 356     82    6   32   3
## 357    107    8   32   3
## 358    129   10   32   3
## 359    159   12   32   3
## 360    179   14   32   3
## 361    221   16   32   3
## 362    263   18   32   3
## 363    291   20   32   3
## 364    305   21   32   3
## 365     39    0   33   3
## 366     50    2   33   3
## 367     63    4   33   3
## 368     77    6   33   3
## 369     96    8   33   3
## 370    111   10   33   3
## 371    137   12   33   3
## 372    144   14   33   3
## 373    151   16   33   3
## 374    146   18   33   3
## 375    156   20   33   3
## 376    147   21   33   3
## 377     41    0   34   3
## 378     49    2   34   3
## 379     63    4   34   3
## 380     85    6   34   3
## 381    107    8   34   3
## 382    134   10   34   3
## 383    164   12   34   3
## 384    186   14   34   3
## 385    235   16   34   3
## 386    294   18   34   3
## 387    327   20   34   3
## 388    341   21   34   3
## 389     41    0   35   3
## 390     53    2   35   3
## 391     64    4   35   3
## 392     87    6   35   3
## 393    123    8   35   3
## 394    158   10   35   3
## 395    201   12   35   3
## 396    238   14   35   3
## 397    287   16   35   3
## 398    332   18   35   3
## 399    361   20   35   3
## 400    373   21   35   3
```

```
## 401       39     0     36     3
## 402       48     2     36     3
## 403       61     4     36     3
## 404       76     6     36     3
## 405       98     8     36     3
## 406      116    10     36     3
## 407      145    12     36     3
## 408      166    14     36     3
## 409      198    16     36     3
## 410      227    18     36     3
## 411      225    20     36     3
## 412      220    21     36     3
## 413       41     0     37     3
## 414       48     2     37     3
## 415       56     4     37     3
## 416       68     6     37     3
## 417       80     8     37     3
## 418       83    10     37     3
## 419      103    12     37     3
## 420      112    14     37     3
## 421      135    16     37     3
## 422      157    18     37     3
## 423      169    20     37     3
## 424      178    21     37     3
## 425       41     0     38     3
## 426       49     2     38     3
## 427       61     4     38     3
## 428       74     6     38     3
## 429       98     8     38     3
## 430      109    10     38     3
## 431      128    12     38     3
## 432      154    14     38     3
## 433      192    16     38     3
## 434      232    18     38     3
## 435      280    20     38     3
## 436      290    21     38     3
## 437       42     0     39     3
## 438       50     2     39     3
## 439       61     4     39     3
## 440       78     6     39     3
## 441       89     8     39     3
## 442      109    10     39     3
## 443      130    12     39     3
## 444      146    14     39     3
## 445      170    16     39     3
## 446      214    18     39     3
## 447      250    20     39     3
## 448      272    21     39     3
## 449       41     0     40     3
## 450       55     2     40     3
## 451       66     4     40     3
## 452       79     6     40     3
## 453      101     8     40     3
## 454      120    10     40     3
```

```
## 455    154    12    40    3
## 456    182    14    40    3
## 457    215    16    40    3
## 458    262    18    40    3
## 459    295    20    40    3
## 460    321    21    40    3
## 461     42     0    41    4
## 462     51     2    41    4
## 463     66     4    41    4
## 464     85     6    41    4
## 465    103     8    41    4
## 466    124    10    41    4
## 467    155    12    41    4
## 468    153    14    41    4
## 469    175    16    41    4
## 470    184    18    41    4
## 471    199    20    41    4
## 472    204    21    41    4
## 473     42     0    42    4
## 474     49     2    42    4
## 475     63     4    42    4
## 476     84     6    42    4
## 477    103     8    42    4
## 478    126    10    42    4
## 479    160    12    42    4
## 480    174    14    42    4
## 481    204    16    42    4
## 482    234    18    42    4
## 483    269    20    42    4
## 484    281    21    42    4
## 485     42     0    43    4
## 486     55     2    43    4
## 487     69     4    43    4
## 488     96     6    43    4
## 489    131     8    43    4
## 490    157    10    43    4
## 491    184    12    43    4
## 492    188    14    43    4
## 493    197    16    43    4
## 494    198    18    43    4
## 495    199    20    43    4
## 496    200    21    43    4
## 497     42     0    44    4
## 498     51     2    44    4
## 499     65     4    44    4
## 500     86     6    44    4
## 501    103     8    44    4
## 502    118    10    44    4
## 503    127    12    44    4
## 504    138    14    44    4
## 505    145    16    44    4
## 506    146    18    44    4
## 507     41     0    45    4
## 508     50     2    45    4
```

```
## 509    61    4    45    4
## 510    78    6    45    4
## 511    98    8    45    4
## 512   117   10    45    4
## 513   135   12    45    4
## 514   141   14    45    4
## 515   147   16    45    4
## 516   174   18    45    4
## 517   197   20    45    4
## 518   196   21    45    4
## 519    40    0    46    4
## 520    52    2    46    4
## 521    62    4    46    4
## 522    82    6    46    4
## 523   101    8    46    4
## 524   120   10    46    4
## 525   144   12    46    4
## 526   156   14    46    4
## 527   173   16    46    4
## 528   210   18    46    4
## 529   231   20    46    4
## 530   238   21    46    4
## 531    41    0    47    4
## 532    53    2    47    4
## 533    66    4    47    4
## 534    79    6    47    4
## 535   100    8    47    4
## 536   123   10    47    4
## 537   148   12    47    4
## 538   157   14    47    4
## 539   168   16    47    4
## 540   185   18    47    4
## 541   210   20    47    4
## 542   205   21    47    4
## 543    39    0    48    4
## 544    50    2    48    4
## 545    62    4    48    4
## 546    80    6    48    4
## 547   104    8    48    4
## 548   125   10    48    4
## 549   154   12    48    4
## 550   170   14    48    4
## 551   222   16    48    4
## 552   261   18    48    4
## 553   303   20    48    4
## 554   322   21    48    4
## 555    40    0    49    4
## 556    53    2    49    4
## 557    64    4    49    4
## 558    85    6    49    4
## 559   108    8    49    4
## 560   128   10    49    4
## 561   152   12    49    4
## 562   166   14    49    4
```

```
## 563      184    16      49      4
## 564      203    18      49      4
## 565      233    20      49      4
## 566      237    21      49      4
## 567       41     0      50      4
## 568       54     2      50      4
## 569       67     4      50      4
## 570       84     6      50      4
## 571      105     8      50      4
## 572      122    10      50      4
## 573      155    12      50      4
## 574      175    14      50      4
## 575      205    16      50      4
## 576      234    18      50      4
## 577      264    20      50      4
## 578      264    21      50      4
```

b

3. Examine the built-in dataset `BOD`. Which of the following is true:

    a. `BOD` is not tidy: it only has six rows.
    b. `BOD` is not tidy: the first column is just an index.
    c. `BOD` is tidy: each row is an observation with two values (time and demand)
    d. `BOD` is tidy: all small datasets are tidy by definition.

BOD

```
##    Time demand
## 1     1    8.3
## 2     2   10.3
## 3     3   19.0
## 4     4   16.0
## 5     5   15.6
## 6     7   19.8
```

b

4. Which of the following built-in datasets is tidy (you can pick more than one):

a.`BJsales` b.`EuStockMarkets` c `DNase` d `Formaldehyde` e.`Orange` f `UCBAdmissions`

BJsales

```
## Time Series:
## Start = 1
## End = 150
## Frequency = 1
##    [1] 200.1 199.5 199.4 198.9 199.0 200.2 198.6 200.0 200.3 201.2 201.6 201.5
##   [13] 201.5 203.5 204.9 207.1 210.5 210.5 209.8 208.8 209.5 213.2 213.7 215.1
##   [25] 218.7 219.8 220.5 223.8 222.8 223.8 221.7 222.3 220.8 219.4 220.1 220.6
##   [37] 218.9 217.8 217.7 215.0 215.3 215.9 216.7 216.7 217.7 218.7 222.9 224.9
```

```
##  [49] 222.2 220.7 220.0 218.7 217.0 215.9 215.8 214.1 212.3 213.9 214.6 213.6
##  [61] 212.1 211.4 213.1 212.9 213.3 211.5 212.3 213.0 211.0 210.7 210.1 211.4
##  [73] 210.0 209.7 208.8 208.8 208.8 210.6 211.9 212.8 212.5 214.8 215.3 217.5
##  [85] 218.8 220.7 222.2 226.7 228.4 233.2 235.7 237.1 240.6 243.8 245.3 246.0
##  [97] 246.3 247.7 247.6 247.8 249.4 249.0 249.9 250.5 251.5 249.0 247.6 248.8
## [109] 250.4 250.7 253.0 253.7 255.0 256.2 256.0 257.4 260.4 260.0 261.3 260.4
## [121] 261.6 260.8 259.8 259.0 258.9 257.4 257.7 257.9 257.4 257.3 257.6 258.9
## [133] 257.8 257.7 257.2 257.5 256.8 257.5 257.0 257.6 257.3 257.5 259.6 261.1
## [145] 262.9 263.3 262.8 261.8 262.2 262.7
```

EuStockMarkets

```
## Time Series:
## Start = c(1991, 130)
## End = c(1998, 169)
## Frequency = 260
##               DAX    SMI    CAC    FTSE
## 1991.496 1628.75 1678.1 1772.8 2443.6
## 1991.500 1613.63 1688.5 1750.5 2460.2
## 1991.504 1606.51 1678.6 1718.0 2448.2
## 1991.508 1621.04 1684.1 1708.1 2470.4
## 1991.512 1618.16 1686.6 1723.1 2484.7
## 1991.515 1610.61 1671.6 1714.3 2466.8
## 1991.519 1630.75 1682.9 1734.5 2487.9
## 1991.523 1640.17 1703.6 1757.4 2508.4
## 1991.527 1635.47 1697.5 1754.0 2510.5
## 1991.531 1645.89 1716.3 1754.3 2497.4
## 1991.535 1647.84 1723.8 1759.8 2532.5
## 1991.538 1638.35 1730.5 1755.5 2556.8
## 1991.542 1629.93 1727.4 1758.1 2561.0
## 1991.546 1621.49 1733.3 1757.5 2547.3
## 1991.550 1624.74 1734.0 1763.5 2541.5
## 1991.554 1627.63 1728.3 1762.8 2558.5
## 1991.558 1631.99 1737.1 1768.9 2587.9
## 1991.562 1621.18 1723.1 1778.1 2580.5
## 1991.565 1613.42 1723.6 1780.1 2579.6
## 1991.569 1604.95 1719.0 1767.7 2589.3
## 1991.573 1605.75 1721.2 1757.9 2595.0
## 1991.577 1616.67 1725.3 1756.6 2595.6
## 1991.581 1619.29 1727.2 1754.7 2588.8
## 1991.585 1620.49 1727.2 1766.8 2591.7
## 1991.588 1619.67 1731.6 1766.5 2601.7
## 1991.592 1623.07 1724.1 1762.2 2585.4
## 1991.596 1613.98 1716.9 1759.5 2573.3
## 1991.600 1631.87 1723.4 1782.4 2597.4
## 1991.604 1630.37 1723.0 1789.5 2600.6
## 1991.608 1633.47 1728.4 1783.5 2570.6
## 1991.612 1626.55 1722.1 1780.4 2569.4
## 1991.615 1650.43 1724.5 1808.8 2584.9
## 1991.619 1650.06 1733.6 1820.3 2608.8
## 1991.623 1654.11 1739.0 1820.3 2617.2
## 1991.627 1653.60 1726.2 1820.3 2621.0
## 1991.631 1501.82 1587.4 1687.5 2540.5
## 1991.635 1524.28 1630.6 1725.6 2554.5
```

```
## 1991.638 1603.65 1685.5 1792.9 2601.9
## 1991.642 1622.49 1701.3 1819.1 2623.0
## 1991.646 1636.68 1718.0 1833.5 2640.7
## 1991.650 1652.10 1726.2 1853.4 2640.7
## 1991.654 1645.81 1716.6 1849.7 2619.8
## 1991.658 1650.36 1725.8 1851.8 2624.2
## 1991.662 1651.55 1737.4 1857.7 2638.2
## 1991.665 1649.88 1736.6 1864.3 2645.7
## 1991.669 1653.52 1732.4 1863.5 2679.6
## 1991.673 1657.51 1731.2 1873.2 2669.0
## 1991.677 1649.55 1726.9 1860.8 2664.6
## 1991.681 1649.09 1727.8 1868.7 2663.3
## 1991.685 1646.41 1720.2 1860.4 2667.4
## 1991.688 1638.65 1715.4 1855.9 2653.2
## 1991.692 1625.80 1708.7 1840.5 2630.8
## 1991.696 1628.64 1713.0 1842.6 2626.6
## 1991.700 1632.22 1713.5 1861.2 2641.9
## 1991.704 1633.65 1718.0 1876.2 2625.8
## 1991.708 1631.17 1701.7 1878.3 2606.0
## 1991.712 1635.80 1701.7 1878.4 2594.4
## 1991.715 1621.27 1684.9 1869.4 2583.6
## 1991.719 1624.70 1687.2 1880.4 2588.7
## 1991.723 1616.13 1690.6 1885.5 2600.3
## 1991.727 1618.12 1684.3 1888.4 2579.5
## 1991.731 1627.80 1679.9 1885.2 2576.6
## 1991.735 1625.79 1672.9 1877.9 2597.8
## 1991.738 1614.80 1663.1 1876.5 2595.6
## 1991.742 1612.80 1669.3 1883.8 2599.0
## 1991.746 1605.47 1664.7 1880.6 2621.7
## 1991.750 1609.32 1672.3 1887.4 2645.6
## 1991.754 1607.48 1687.7 1878.3 2644.2
## 1991.758 1607.48 1686.8 1867.1 2625.6
## 1991.762 1604.89 1686.6 1851.9 2624.6
## 1991.765 1589.12 1675.8 1843.6 2596.2
## 1991.769 1582.27 1677.4 1848.1 2599.5
## 1991.773 1567.99 1673.2 1843.4 2584.1
## 1991.777 1568.16 1665.0 1843.6 2570.8
## 1991.781 1569.71 1671.3 1833.8 2555.0
## 1991.785 1571.74 1672.4 1833.4 2574.5
## 1991.788 1585.41 1676.2 1856.9 2576.7
## 1991.792 1570.01 1692.6 1863.4 2579.0
## 1991.796 1561.89 1696.5 1855.5 2588.7
## 1991.800 1565.18 1716.1 1864.2 2601.1
## 1991.804 1570.34 1713.3 1846.0 2575.7
## 1991.808 1577.00 1705.1 1836.8 2559.5
## 1991.812 1590.29 1711.3 1830.4 2561.1
## 1991.815 1572.72 1709.8 1831.6 2528.3
## 1991.819 1572.07 1688.6 1834.8 2514.7
## 1991.823 1579.19 1698.9 1852.1 2558.5
## 1991.827 1588.73 1700.0 1849.8 2553.3
## 1991.831 1586.01 1693.0 1861.8 2577.1
## 1991.835 1579.77 1683.9 1856.7 2566.0
## 1991.838 1572.58 1679.2 1856.7 2549.5
## 1991.842 1568.09 1673.9 1841.5 2527.8
```

```
## 1991.846 1578.21 1683.9 1846.9 2540.9
## 1991.850 1573.94 1688.4 1836.1 2534.2
## 1991.854 1582.06 1693.9 1838.6 2538.0
## 1991.858 1610.18 1720.9 1857.6 2559.0
## 1991.862 1605.16 1717.9 1857.6 2554.9
## 1991.865 1623.84 1733.6 1858.4 2575.5
## 1991.869 1615.26 1729.7 1846.8 2546.5
## 1991.873 1627.08 1735.6 1868.5 2561.6
## 1991.877 1626.97 1734.1 1863.2 2546.6
## 1991.881 1605.70 1699.3 1808.3 2502.9
## 1991.885 1589.70 1678.6 1765.1 2463.1
## 1991.888 1589.70 1675.5 1763.5 2472.6
## 1991.892 1603.26 1670.1 1766.0 2463.5
## 1991.896 1599.75 1652.2 1741.3 2446.3
## 1991.900 1590.86 1635.0 1743.3 2456.2
## 1991.904 1603.50 1654.9 1769.0 2471.5
## 1991.908 1589.86 1642.0 1757.9 2447.5
## 1991.912 1587.92 1638.7 1754.9 2428.6
## 1991.915 1571.06 1622.6 1739.7 2420.2
## 1991.919 1549.81 1596.1 1708.8 2414.9
## 1991.923 1549.36 1612.4 1722.2 2420.2
## 1991.927 1554.65 1625.0 1713.9 2423.8
## 1991.931 1557.52 1610.5 1703.2 2407.0
## 1991.935 1555.31 1606.6 1685.7 2388.7
## 1991.938 1559.76 1610.7 1663.4 2409.6
## 1991.942 1548.44 1603.1 1636.9 2392.0
## 1991.946 1543.99 1591.5 1645.6 2380.2
## 1991.950 1550.21 1605.2 1671.6 2423.3
## 1991.954 1557.03 1621.4 1688.3 2451.6
## 1991.958 1551.78 1622.5 1696.8 2440.8
## 1991.962 1562.89 1626.6 1711.7 2432.9
## 1991.965 1570.28 1627.4 1706.2 2413.6
## 1991.969 1559.26 1614.9 1684.2 2391.6
## 1991.973 1545.87 1602.3 1648.5 2358.1
## 1991.977 1542.77 1598.3 1633.6 2345.4
## 1991.981 1542.77 1627.0 1699.1 2384.4
## 1991.985 1542.77 1627.0 1699.1 2384.4
## 1991.988 1542.77 1627.0 1722.5 2384.4
## 1991.992 1564.27 1655.7 1720.7 2418.7
## 1991.996 1577.26 1670.1 1741.9 2420.0
## 1992.000 1577.26 1670.1 1765.7 2493.1
## 1992.004 1577.26 1670.1 1765.7 2493.1
## 1992.008 1598.19 1670.1 1749.9 2492.8
## 1992.012 1604.05 1704.0 1770.3 2504.1
## 1992.015 1604.69 1711.8 1787.6 2493.2
## 1992.019 1593.65 1700.5 1778.7 2482.9
## 1992.023 1581.68 1690.3 1785.6 2467.1
## 1992.027 1599.14 1715.4 1833.9 2497.9
## 1992.031 1613.82 1723.5 1837.4 2477.9
## 1992.035 1620.45 1719.4 1824.3 2490.1
## 1992.038 1629.51 1734.4 1843.8 2516.3
## 1992.042 1663.70 1772.8 1873.6 2537.1
## 1992.046 1664.09 1760.3 1860.2 2541.6
## 1992.050 1669.29 1747.2 1860.2 2536.7
```

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## 1992.054 1685.14 1750.2 1865.9 2544.9
## 1992.058 1687.07 1755.3 1867.9 2543.4
## 1992.062 1680.13 1754.6 1841.3 2522.0
## 1992.065 1671.84 1751.2 1838.7 2525.3
## 1992.069 1669.52 1752.5 1849.9 2510.4
## 1992.073 1686.71 1769.4 1869.3 2539.9
## 1992.077 1685.51 1767.6 1890.6 2552.0
## 1992.081 1671.01 1750.0 1879.6 2546.5
## 1992.085 1683.06 1747.1 1873.9 2550.8
## 1992.088 1685.70 1753.5 1875.3 2571.2
## 1992.092 1685.66 1752.8 1857.0 2560.2
## 1992.096 1678.77 1752.9 1856.5 2556.8
## 1992.100 1685.85 1764.7 1865.8 2547.1
## 1992.104 1683.71 1776.8 1860.6 2534.3
## 1992.108 1686.59 1779.3 1861.6 2517.2
## 1992.112 1683.73 1785.1 1865.6 2538.4
## 1992.115 1679.14 1798.2 1864.1 2537.1
## 1992.119 1685.03 1794.1 1861.6 2523.7
## 1992.123 1680.81 1795.2 1876.5 2522.6
## 1992.127 1676.17 1780.4 1865.1 2513.9
## 1992.131 1688.46 1789.5 1882.1 2541.0
## 1992.135 1696.55 1794.2 1912.2 2555.9
## 1992.138 1690.24 1784.4 1915.4 2536.7
## 1992.142 1711.35 1800.1 1951.2 2543.4
## 1992.146 1711.29 1804.0 1962.4 2542.3
## 1992.150 1729.86 1816.2 1976.5 2559.7
## 1992.154 1716.63 1810.5 1953.5 2546.8
## 1992.158 1743.36 1821.9 1981.3 2565.0
## 1992.162 1745.17 1828.2 1985.1 2562.0
## 1992.165 1746.76 1840.6 1983.4 2562.1
## 1992.169 1749.29 1841.1 1979.7 2554.3
## 1992.173 1763.86 1846.3 1983.8 2565.4
## 1992.177 1762.27 1850.0 1988.1 2558.4
## 1992.181 1762.29 1839.0 1973.0 2538.3
## 1992.185 1746.77 1820.2 1966.9 2533.1
## 1992.188 1753.50 1815.2 1976.3 2550.7
## 1992.192 1753.21 1820.6 1993.9 2574.8
## 1992.196 1739.88 1807.1 1968.0 2522.4
## 1992.200 1723.92 1791.4 1941.8 2493.3
## 1992.204 1734.42 1806.2 1947.1 2476.0
## 1992.208 1723.13 1798.7 1929.2 2470.7
## 1992.212 1732.92 1818.2 1943.6 2491.2
## 1992.215 1729.89 1820.5 1928.2 2464.7
## 1992.219 1725.74 1833.3 1922.0 2467.6
## 1992.223 1730.90 1837.1 1919.1 2456.6
## 1992.227 1714.17 1818.2 1884.6 2441.0
## 1992.231 1716.20 1824.1 1896.3 2458.7
## 1992.235 1719.06 1830.1 1928.3 2464.9
## 1992.238 1718.21 1835.6 1934.8 2472.2
## 1992.242 1698.84 1828.7 1923.5 2447.9
## 1992.246 1714.76 1839.2 1943.8 2452.9
## 1992.250 1718.35 1837.2 1942.4 2440.1
## 1992.254 1706.69 1826.7 1928.1 2408.6
## 1992.258 1723.37 1838.0 1942.0 2405.4
```

```
## 1992.262 1716.18 1829.1 1942.7 2382.7
## 1992.265 1738.78 1843.1 1974.8 2400.9
## 1992.269 1737.41 1850.5 1975.4 2404.2
## 1992.273 1714.77 1827.1 1907.5 2393.2
## 1992.277 1724.24 1829.1 1943.6 2436.4
## 1992.281 1733.77 1848.0 1974.1 2572.6
## 1992.285 1729.96 1840.5 1963.3 2591.0
## 1992.288 1734.46 1853.8 1972.3 2600.5
## 1992.292 1744.35 1874.1 1990.7 2640.2
## 1992.296 1746.88 1871.3 1978.2 2638.6
## 1992.300 1746.88 1871.3 1978.2 2638.6
## 1992.304 1746.88 1871.3 1978.2 2638.6
## 1992.308 1747.47 1860.5 1980.4 2625.8
## 1992.312 1753.10 1874.7 1983.7 2607.8
## 1992.315 1745.17 1880.1 1978.1 2609.8
## 1992.319 1745.72 1874.7 1984.9 2643.0
## 1992.323 1742.92 1875.6 1995.7 2658.2
## 1992.327 1731.68 1859.5 2006.6 2651.0
## 1992.331 1731.18 1874.2 2036.7 2664.9
## 1992.335 1728.09 1880.1 2031.1 2654.1
## 1992.338 1728.09 1880.1 2031.1 2659.8
## 1992.342 1731.29 1907.7 2041.6 2659.8
## 1992.346 1733.82 1920.5 2046.9 2662.2
## 1992.350 1745.78 1937.3 2047.2 2698.7
## 1992.354 1752.57 1936.8 2063.4 2701.9
## 1992.358 1748.13 1949.1 2063.4 2725.7
## 1992.362 1750.70 1963.7 2077.5 2737.8
## 1992.365 1747.91 1950.8 2063.6 2722.4
## 1992.369 1745.79 1953.5 2053.2 2720.5
## 1992.373 1735.34 1945.0 2017.0 2694.7
## 1992.377 1719.92 1921.1 2024.0 2682.6
## 1992.381 1763.59 1939.1 2051.6 2703.6
## 1992.385 1766.76 1928.0 2023.1 2700.6
## 1992.388 1785.40 1933.4 2030.8 2711.9
## 1992.392 1783.56 1925.7 2016.8 2702.0
## 1992.396 1804.42 1931.7 2045.1 2715.0
## 1992.400 1812.33 1928.7 2046.3 2715.0
## 1992.404 1799.51 1924.5 2029.6 2704.6
## 1992.408 1792.80 1914.2 2014.1 2698.6
## 1992.412 1792.80 1914.2 2014.1 2694.2
## 1992.415 1806.36 1920.6 2033.3 2707.6
## 1992.419 1798.23 1923.3 2017.4 2697.6
## 1992.423 1800.62 1930.4 2024.9 2705.9
## 1992.427 1786.19 1915.2 1992.6 2680.9
## 1992.431 1791.35 1916.9 1994.9 2681.9
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## 1998.165 4583.03 6986.7 3262.5 5718.5
## 1998.169 4610.66 6986.1 3273.5 5702.8
## 1998.173 4604.55 6945.0 3262.3 5651.0
## 1998.177 4704.58 7065.4 3348.2 5745.1
## 1998.181 4695.78 7118.6 3397.0 5764.8
## 1998.185 4693.86 7153.1 3421.9 5767.3
## 1998.188 4781.62 7273.0 3446.7 5820.6
## 1998.192 4759.62 7259.5 3414.9 5807.7
## 1998.196 4690.52 7130.5 3381.3 5733.1
## 1998.200 4676.42 7077.3 3395.8 5695.6
## 1998.204 4762.71 7197.2 3483.2 5782.9
## 1998.208 4828.89 7187.5 3525.9 5818.9
## 1998.212 4852.22 7246.5 3521.5 5828.5
## 1998.215 4862.41 7276.7 3539.4 5829.8
## 1998.219 4838.67 7267.9 3526.6 5794.8
## 1998.223 4872.24 7328.0 3540.2 5782.3
## 1998.227 4905.59 7261.2 3598.3 5785.1
## 1998.231 4945.91 7236.5 3661.3 5834.9
## 1998.235 4908.55 7132.4 3652.5 5903.6
## 1998.238 4949.91 7143.8 3688.7 5997.9
## 1998.242 5045.16 7300.5 3688.9 5956.3
## 1998.246 5014.13 7341.0 3680.1 5947.0
## 1998.250 5064.35 7407.4 3738.5 5983.7
## 1998.254 5114.13 7472.1 3818.7 5967.8
## 1998.258 5029.00 7415.9 3783.8 5905.6
## 1998.262 5066.90 7530.3 3810.2 5939.3
## 1998.265 5069.89 7536.3 3800.2 5911.9
## 1998.269 5097.25 7585.5 3875.3 5932.2
## 1998.273 5135.35 7615.5 3883.3 6017.6
## 1998.277 5179.04 7638.8 3935.9 6052.8
## 1998.281 5254.32 7725.9 3932.0 6064.2
```

```
## 1998.285 5345.89 7827.7 3986.8 6105.8
## 1998.288 5309.67 7744.3 3903.3 6094.0
## 1998.292 5267.35 7588.1 3873.9 6055.2
## 1998.296 5312.25 7624.1 3894.5 6105.5
## 1998.300 5312.25 7624.1 3894.5 6105.5
## 1998.304 5312.25 7624.1 3894.5 6105.5
## 1998.308 5367.98 7662.9 3867.7 6104.1
## 1998.312 5359.24 7616.3 3884.6 6074.1
## 1998.315 5292.97 7500.1 3845.9 6002.0
## 1998.319 5326.63 7453.7 3861.6 5922.2
## 1998.323 5407.93 7500.1 3885.7 5954.1
## 1998.327 5373.80 7369.1 3860.4 5955.0
## 1998.331 5312.28 7308.9 3835.1 5931.1
## 1998.335 5262.57 7265.5 3822.1 5898.1
## 1998.338 5144.42 7232.3 3788.7 5863.9
## 1998.342 5002.71 7053.5 3689.4 5722.4
## 1998.346 5110.88 7180.1 3777.2 5806.6
## 1998.350 5083.80 7241.8 3726.2 5833.1
## 1998.354 5241.23 7401.4 3867.9 5928.3
## 1998.358 5241.23 7401.4 3867.9 6011.3
## 1998.362 5337.75 7640.8 3979.3 6011.3
## 1998.365 5226.20 7596.2 3945.5 5986.5
## 1998.369 5264.62 7610.8 3947.5 5992.4
## 1998.373 5164.89 7536.0 3912.8 5938.0
## 1998.377 5270.61 7587.1 3912.8 5969.8
## 1998.381 5348.75 7677.5 4007.3 6028.3
## 1998.385 5307.82 7627.3 3986.1 5956.7
## 1998.388 5371.99 7582.8 4018.5 5972.9
## 1998.392 5374.11 7550.6 4012.0 5948.5
## 1998.396 5414.31 7519.4 3990.2 5917.8
## 1998.400 5343.66 7371.4 3945.3 5826.2
## 1998.404 5441.00 7483.2 3980.8 5877.8
## 1998.408 5514.51 7495.8 4047.9 5907.4
## 1998.412 5514.51 7495.8 4047.9 5935.6
## 1998.415 5530.19 7542.7 4049.8 5955.6
## 1998.419 5592.46 7657.1 4108.7 5955.6
## 1998.423 5639.89 7731.9 4115.9 5970.7
## 1998.427 5466.88 7633.5 4017.4 5870.2
## 1998.431 5507.36 7605.0 4014.9 5862.3
## 1998.435 5556.99 7656.1 4041.2 5870.7
## 1998.438 5556.99 7656.1 4041.2 5837.9
## 1998.442 5583.83 7657.5 4087.0 5842.3
## 1998.446 5640.42 7676.3 4149.4 5898.4
## 1998.450 5605.38 7592.9 4119.0 5860.8
## 1998.454 5724.75 7699.5 4185.1 5947.3
## 1998.458 5787.05 7743.4 4204.6 6037.8
## 1998.462 5773.77 7716.8 4201.9 6019.8
## 1998.465 5799.22 7652.6 4208.6 5987.4
## 1998.469 5799.22 7498.4 4141.6 5852.5
## 1998.473 5631.34 7417.4 4050.8 5769.8
## 1998.477 5581.24 7342.7 4005.3 5715.7
## 1998.481 5621.71 7388.7 4013.3 5729.7
## 1998.485 5742.83 7562.7 4092.9 5832.7
## 1998.488 5689.89 7488.0 4052.3 5812.1
```

```
## 1998.492 5644.22 7518.6 4027.3 5748.1
## 1998.496 5648.11 7511.8 4018.6 5712.4
## 1998.500 5748.34 7624.8 4065.0 5772.0
## 1998.504 5784.40 7667.9 4126.3 5804.9
## 1998.508 5886.72 7794.7 4203.8 5858.9
## 1998.512 5870.49 7816.9 4215.7 5877.4
## 1998.515 5933.73 7881.9 4248.2 5884.5
## 1998.519 5841.83 7882.0 4203.5 5832.5
## 1998.523 5910.51 8038.2 4260.7 5919.9
## 1998.527 5905.15 8047.3 4252.1 5960.2
## 1998.531 5961.45 8099.0 4304.4 5988.4
## 1998.535 5942.06 8166.0 4311.1 5990.3
## 1998.538 5975.88 8160.0 4333.1 6003.4
## 1998.542 6018.89 8227.2 4339.9 6009.6
## 1998.546 6000.84 8205.0 4319.2 5969.7
## 1998.550 6001.24 8192.4 4256.4 5927.9
## 1998.554 6023.31 8141.9 4256.4 5958.2
## 1998.558 6101.90 8180.5 4256.4 6100.2
## 1998.562 6106.10 8158.1 4344.3 6151.5
## 1998.565 6108.00 8126.5 4358.1 6116.8
## 1998.569 6162.86 8288.2 4388.5 6174.0
## 1998.573 6186.09 8400.8 4368.9 6179.0
## 1998.577 6184.10 8412.0 4322.1 6132.7
## 1998.581 6081.11 8340.7 4220.1 5989.6
## 1998.585 6043.82 8229.2 4235.9 5976.2
## 1998.588 6040.58 8205.7 4205.4 5892.3
## 1998.592 5854.35 7998.7 4139.5 5836.1
## 1998.596 5867.52 8093.0 4122.4 5835.8
## 1998.600 5828.74 8102.7 4139.2 5844.1
## 1998.604 5906.33 8205.5 4197.6 5910.7
## 1998.608 5861.19 8239.5 4177.3 5837.0
## 1998.612 5774.38 8139.2 4095.0 5809.7
## 1998.615 5718.70 8170.2 4047.9 5736.1
## 1998.619 5614.77 7943.2 3976.4 5632.5
## 1998.623 5528.12 7846.2 3968.6 5594.1
## 1998.627 5598.32 7952.9 4041.9 5680.4
## 1998.631 5460.43 7721.3 3939.5 5587.6
## 1998.635 5285.78 7447.9 3846.0 5432.8
## 1998.638 5386.94 7607.5 3945.7 5462.2
## 1998.642 5355.03 7552.6 3951.7 5399.5
## 1998.646 5473.72 7676.3 3995.0 5455.0
```

DNase

```
##     Run        conc density
## 1     1  0.04882812   0.017
## 2     1  0.04882812   0.018
## 3     1  0.19531250   0.121
## 4     1  0.19531250   0.124
## 5     1  0.39062500   0.206
## 6     1  0.39062500   0.215
## 7     1  0.78125000   0.377
## 8     1  0.78125000   0.374
## 9     1  1.56250000   0.614
```

```
## 10   1  1.56250000    0.609
## 11   1  3.12500000    1.019
## 12   1  3.12500000    1.001
## 13   1  6.25000000    1.334
## 14   1  6.25000000    1.364
## 15   1 12.50000000    1.730
## 16   1 12.50000000    1.710
## 17   2  0.04882812    0.045
## 18   2  0.04882812    0.050
## 19   2  0.19531250    0.137
## 20   2  0.19531250    0.123
## 21   2  0.39062500    0.225
## 22   2  0.39062500    0.207
## 23   2  0.78125000    0.401
## 24   2  0.78125000    0.383
## 25   2  1.56250000    0.672
## 26   2  1.56250000    0.681
## 27   2  3.12500000    1.116
## 28   2  3.12500000    1.078
## 29   2  6.25000000    1.554
## 30   2  6.25000000    1.526
## 31   2 12.50000000    1.932
## 32   2 12.50000000    1.914
## 33   3  0.04882812    0.070
## 34   3  0.04882812    0.068
## 35   3  0.19531250    0.173
## 36   3  0.19531250    0.165
## 37   3  0.39062500    0.277
## 38   3  0.39062500    0.248
## 39   3  0.78125000    0.434
## 40   3  0.78125000    0.426
## 41   3  1.56250000    0.703
## 42   3  1.56250000    0.689
## 43   3  3.12500000    1.067
## 44   3  3.12500000    1.077
## 45   3  6.25000000    1.629
## 46   3  6.25000000    1.479
## 47   3 12.50000000    2.003
## 48   3 12.50000000    1.884
## 49   4  0.04882812    0.011
## 50   4  0.04882812    0.016
## 51   4  0.19531250    0.118
## 52   4  0.19531250    0.108
## 53   4  0.39062500    0.200
## 54   4  0.39062500    0.206
## 55   4  0.78125000    0.364
## 56   4  0.78125000    0.360
## 57   4  1.56250000    0.620
## 58   4  1.56250000    0.640
## 59   4  3.12500000    0.979
## 60   4  3.12500000    0.973
## 61   4  6.25000000    1.424
## 62   4  6.25000000    1.399
## 63   4 12.50000000    1.740
```

```
## 64    4 12.50000000    1.732
## 65    5  0.04882812    0.035
## 66    5  0.04882812    0.035
## 67    5  0.19531250    0.132
## 68    5  0.19531250    0.135
## 69    5  0.39062500    0.224
## 70    5  0.39062500    0.220
## 71    5  0.78125000    0.385
## 72    5  0.78125000    0.390
## 73    5  1.56250000    0.658
## 74    5  1.56250000    0.647
## 75    5  3.12500000    1.060
## 76    5  3.12500000    1.031
## 77    5  6.25000000    1.425
## 78    5  6.25000000    1.409
## 79    5 12.50000000    1.750
## 80    5 12.50000000    1.738
## 81    6  0.04882812    0.086
## 82    6  0.04882812    0.103
## 83    6  0.19531250    0.191
## 84    6  0.19531250    0.189
## 85    6  0.39062500    0.272
## 86    6  0.39062500    0.277
## 87    6  0.78125000    0.440
## 88    6  0.78125000    0.426
## 89    6  1.56250000    0.686
## 90    6  1.56250000    0.676
## 91    6  3.12500000    1.062
## 92    6  3.12500000    1.072
## 93    6  6.25000000    1.424
## 94    6  6.25000000    1.459
## 95    6 12.50000000    1.768
## 96    6 12.50000000    1.806
## 97    7  0.04882812    0.094
## 98    7  0.04882812    0.092
## 99    7  0.19531250    0.182
## 100   7  0.19531250    0.182
## 101   7  0.39062500    0.282
## 102   7  0.39062500    0.273
## 103   7  0.78125000    0.444
## 104   7  0.78125000    0.439
## 105   7  1.56250000    0.686
## 106   7  1.56250000    0.668
## 107   7  3.12500000    1.052
## 108   7  3.12500000    1.035
## 109   7  6.25000000    1.409
## 110   7  6.25000000    1.392
## 111   7 12.50000000    1.759
## 112   7 12.50000000    1.739
## 113   8  0.04882812    0.054
## 114   8  0.04882812    0.054
## 115   8  0.19531250    0.152
## 116   8  0.19531250    0.148
## 117   8  0.39062500    0.226
```

```
## 118   8  0.39062500   0.222
## 119   8  0.78125000   0.392
## 120   8  0.78125000   0.383
## 121   8  1.56250000   0.658
## 122   8  1.56250000   0.644
## 123   8  3.12500000   1.043
## 124   8  3.12500000   1.002
## 125   8  6.25000000   1.466
## 126   8  6.25000000   1.381
## 127   8 12.50000000   1.743
## 128   8 12.50000000   1.724
## 129   9  0.04882812   0.032
## 130   9  0.04882812   0.043
## 131   9  0.19531250   0.142
## 132   9  0.19531250   0.155
## 133   9  0.39062500   0.239
## 134   9  0.39062500   0.242
## 135   9  0.78125000   0.420
## 136   9  0.78125000   0.395
## 137   9  1.56250000   0.624
## 138   9  1.56250000   0.705
## 139   9  3.12500000   1.046
## 140   9  3.12500000   1.026
## 141   9  6.25000000   1.398
## 142   9  6.25000000   1.405
## 143   9 12.50000000   1.693
## 144   9 12.50000000   1.729
## 145  10  0.04882812   0.052
## 146  10  0.04882812   0.094
## 147  10  0.19531250   0.164
## 148  10  0.19531250   0.166
## 149  10  0.39062500   0.259
## 150  10  0.39062500   0.256
## 151  10  0.78125000   0.439
## 152  10  0.78125000   0.439
## 153  10  1.56250000   0.690
## 154  10  1.56250000   0.701
## 155  10  3.12500000   1.042
## 156  10  3.12500000   1.075
## 157  10  6.25000000   1.340
## 158  10  6.25000000   1.406
## 159  10 12.50000000   1.699
## 160  10 12.50000000   1.708
## 161  11  0.04882812   0.047
## 162  11  0.04882812   0.057
## 163  11  0.19531250   0.159
## 164  11  0.19531250   0.155
## 165  11  0.39062500   0.246
## 166  11  0.39062500   0.252
## 167  11  0.78125000   0.427
## 168  11  0.78125000   0.411
## 169  11  1.56250000   0.704
## 170  11  1.56250000   0.684
## 171  11  3.12500000   0.994
```

```
## 172  11  3.12500000   0.980
## 173  11  6.25000000   1.421
## 174  11  6.25000000   1.385
## 175  11 12.50000000   1.715
## 176  11 12.50000000   1.721
```

Formaldehyde

```
##   carb optden
## 1  0.1  0.086
## 2  0.3  0.269
## 3  0.5  0.446
## 4  0.6  0.538
## 5  0.7  0.626
## 6  0.9  0.782
```

Orange

```
##    Tree  age circumference
## 1     1  118            30
## 2     1  484            58
## 3     1  664            87
## 4     1 1004           115
## 5     1 1231           120
## 6     1 1372           142
## 7     1 1582           145
## 8     2  118            33
## 9     2  484            69
## 10    2  664           111
## 11    2 1004           156
## 12    2 1231           172
## 13    2 1372           203
## 14    2 1582           203
## 15    3  118            30
## 16    3  484            51
## 17    3  664            75
## 18    3 1004           108
## 19    3 1231           115
## 20    3 1372           139
## 21    3 1582           140
## 22    4  118            32
## 23    4  484            62
## 24    4  664           112
## 25    4 1004           167
## 26    4 1231           179
## 27    4 1372           209
## 28    4 1582           214
## 29    5  118            30
## 30    5  484            49
## 31    5  664            81
## 32    5 1004           125
## 33    5 1231           142
## 34    5 1372           174
## 35    5 1582           177
```

```
UCBAdmissions
```

```
## , , Dept = A
##
##          Gender
## Admit      Male Female
##   Admitted  512     89
##   Rejected  313     19
##
## , , Dept = B
##
##          Gender
## Admit      Male Female
##   Admitted  353     17
##   Rejected  207      8
##
## , , Dept = C
##
##          Gender
## Admit      Male Female
##   Admitted  120    202
##   Rejected  205    391
##
## , , Dept = D
##
##          Gender
## Admit      Male Female
##   Admitted  138    131
##   Rejected  279    244
##
## , , Dept = E
##
##          Gender
## Admit      Male Female
##   Admitted   53     94
##   Rejected  138    299
##
## , , Dept = F
##
##          Gender
## Admit      Male Female
##   Admitted   22     24
##   Rejected  351    317
```

c,d,e

4.3 Manipulating data frames

The **dplyr** package from the **tidyverse** introduces functions that perform some of the most common operations when working with data frames and uses names for these functions that are relatively easy to remember. For instance, to change the data table by adding a new column, we use `mutate`. To filter the data table to a subset of rows, we use `filter`. Finally, to subset the data by selecting specific columns, we use `select`.

4.3.1 Adding a column with `mutate`

We want all the necessary information for our analysis to be included in the data table. So the first task is to add the murder rates to our murders data frame. The function `mutate` takes the data frame as a first argument and the name and values of the variable as a second argument using the convention `name = values`. So, to add murder rates, we use:

```
library(dslabs)
data("murders")
murders <- mutate(murders, rate = total / population * 100000)
```

Notice that here we used `total` and `population` inside the function, which are objects that are **not** defined in our workspace. But why don't we get an error?

This is one of **dply**r's main features. Functions in this package, such as `mutate`, know to look for variables in the data frame provided in the first argument. In the call to mutate above, `total` will have the values in `murders$total`. This approach makes the code much more readable.

We can see that the new column is added:

```
head(murders)
```

```
##         state abb region population total     rate
## 1     Alabama  AL  South    4779736   135 2.824424
## 2      Alaska  AK   West     710231    19 2.675186
## 3     Arizona  AZ   West    6392017   232 3.629527
## 4    Arkansas  AR  South    2915918    93 3.189390
## 5  California  CA   West   37253956  1257 3.374138
## 6    Colorado  CO   West    5029196    65 1.292453
```

```
#>         state abb region population total rate
#> 1     Alabama  AL  South    4779736   135 2.82
#> 2      Alaska  AK   West     710231    19 2.68
#> 3     Arizona  AZ   West    6392017   232 3.63
#> 4    Arkansas  AR  South    2915918    93 3.19
#> 5  California  CA   West   37253956  1257 3.37
#> 6    Colorado  CO   West    5029196    65 1.29
```

Although we have overwritten the original `murders` object, this does not change the object that loaded with `data(murders)`. If we load the `murders` data again, the original will overwrite our mutated version.

4.3.2 Subsetting with `filter`

Now suppose that we want to filter the data table to only show the entries for which the murder rate is lower than 0.71. To do this we use the `filter` function, which takes the data table as the first argument and then the conditional statement as the second. Like `mutate`, we can use the unquoted variable names from `murders` inside the function and it will know we mean the columns and not objects in the workspace.

```
filter(murders, rate <= 0.71)
```

```
##     state abb region population total      rate
## 1  Hawaii  HI   West    1360301     7 0.5145920
```

```
## 2          Iowa  IA North Central    3046355   21 0.6893484
## 3 New Hampshire  NH     Northeast    1316470    5 0.3798036
## 4  North Dakota  ND North Central     672591    4 0.5947151
## 5       Vermont  VT     Northeast     625741    2 0.3196211
```

```
#>           state abb        region population total  rate
#> 1        Hawaii  HI          West    1360301     7 0.515
#> 2          Iowa  IA North Central    3046355    21 0.689
#> 3 New Hampshire  NH     Northeast    1316470     5 0.380
#> 4  North Dakota  ND North Central     672591     4 0.595
#> 5       Vermont  VT     Northeast     625741     2 0.320
```

4.3.3 Selecting columns with `select`

Although our data table only has six columns, some data tables include hundreds. If we want to view just a few, we can use the **dplyr** `select` function. In the code below we select three columns, assign this to a new object and then filter the new object:

```
new_table <- select(murders, state, region, rate)
filter(new_table, rate <= 0.71)
```

```
##           state        region      rate
## 1        Hawaii          West 0.5145920
## 2          Iowa North Central 0.6893484
## 3 New Hampshire     Northeast 0.3798036
## 4  North Dakota North Central 0.5947151
## 5       Vermont     Northeast 0.3196211
```

```
#>           state        region  rate
#> 1        Hawaii          West 0.515
#> 2          Iowa North Central 0.689
#> 3 New Hampshire     Northeast 0.380
#> 4  North Dakota North Central 0.595
#> 5       Vermont     Northeast 0.320
```

In the call to select, the first argument murders is an object, but state, region, and rate are variable names.

4.4 Exercises

1. Load the **dplyr** package and the murders dataset.

```
library(dplyr)
library(dslabs)
data(murders)
```

You can add columns using the **dplyr** function `mutate`. This function is aware of the column names and inside the function you can call them unquoted:

```
murders <- mutate(murders, population_in_millions = population / 10^6)
```

We can write `population` rather than `murders$population`. The function `mutate` knows we are grabbing columns from `murders`.

Use the function mutate to add a murders column named rate with the per 100,000 murder rate as in the example code above. Make sure you redefine murders as done in the example code above (murders <- [your code]) so we can keep using this variable.

```
murders <- mutate(murders, rate = total / population * 100000)
murders
```

```
##                     state abb       region population total
## 1                 Alabama  AL        South    4779736   135
## 2                  Alaska  AK         West     710231    19
## 3                 Arizona  AZ         West    6392017   232
## 4                Arkansas  AR        South    2915918    93
## 5              California  CA         West   37253956  1257
## 6                Colorado  CO         West    5029196    65
## 7             Connecticut  CT    Northeast    3574097    97
## 8                Delaware  DE        South     897934    38
## 9    District of Columbia  DC        South     601723    99
## 10                Florida  FL        South   19687653   669
## 11                Georgia  GA        South    9920000   376
## 12                 Hawaii  HI         West    1360301     7
## 13                  Idaho  ID         West    1567582    12
## 14               Illinois  IL North Central   12830632   364
## 15                Indiana  IN North Central    6483802   142
## 16                   Iowa  IA North Central    3046355    21
## 17                 Kansas  KS North Central    2853118    63
## 18               Kentucky  KY        South    4339367   116
## 19              Louisiana  LA        South    4533372   351
## 20                  Maine  ME    Northeast    1328361    11
## 21               Maryland  MD        South    5773552   293
## 22          Massachusetts  MA    Northeast    6547629   118
## 23               Michigan  MI North Central    9883640   413
## 24              Minnesota  MN North Central    5303925    53
## 25            Mississippi  MS        South    2967297   120
## 26               Missouri  MO North Central    5988927   321
## 27                Montana  MT         West     989415    12
## 28               Nebraska  NE North Central    1826341    32
## 29                 Nevada  NV         West    2700551    84
## 30          New Hampshire  NH    Northeast    1316470     5
## 31             New Jersey  NJ    Northeast    8791894   246
## 32             New Mexico  NM         West    2059179    67
## 33               New York  NY    Northeast   19378102   517
## 34         North Carolina  NC        South    9535483   286
## 35           North Dakota  ND North Central     672591     4
## 36                   Ohio  OH North Central   11536504   310
## 37               Oklahoma  OK        South    3751351   111
## 38                 Oregon  OR         West    3831074    36
## 39           Pennsylvania  PA    Northeast   12702379   457
## 40           Rhode Island  RI    Northeast    1052567    16
## 41         South Carolina  SC        South    4625364   207
## 42           South Dakota  SD North Central     814180     8
## 43              Tennessee  TN        South    6346105   219
```

```
## 44             Texas  TX        South  25145561  805
## 45              Utah  UT         West   2763885   22
## 46           Vermont  VT    Northeast    625741    2
## 47          Virginia  VA        South   8001024  250
## 48        Washington  WA         West   6724540   93
## 49     West Virginia  WV        South   1852994   27
## 50         Wisconsin  WI North Central   5686986   97
## 51           Wyoming  WY         West    563626    5
##    population_in_millions        rate
## 1                4.779736   2.8244238
## 2                0.710231   2.6751860
## 3                6.392017   3.6295273
## 4                2.915918   3.1893901
## 5               37.253956   3.3741383
## 6                5.029196   1.2924531
## 7                3.574097   2.7139722
## 8                0.897934   4.2319369
## 9                0.601723  16.4527532
## 10              19.687653   3.3980688
## 11               9.920000   3.7903226
## 12               1.360301   0.5145920
## 13               1.567582   0.7655102
## 14              12.830632   2.8369608
## 15               6.483802   2.1900730
## 16               3.046355   0.6893484
## 17               2.853118   2.2081106
## 18               4.339367   2.6732010
## 19               4.533372   7.7425810
## 20               1.328361   0.8280881
## 21               5.773552   5.0748655
## 22               6.547629   1.8021791
## 23               9.883640   4.1786225
## 24               5.303925   0.9992600
## 25               2.967297   4.0440846
## 26               5.988927   5.3598917
## 27               0.989415   1.2128379
## 28               1.826341   1.7521372
## 29               2.700551   3.1104763
## 30               1.316470   0.3798036
## 31               8.791894   2.7980319
## 32               2.059179   3.2537239
## 33              19.378102   2.6679599
## 34               9.535483   2.9993237
## 35               0.672591   0.5947151
## 36              11.536504   2.6871225
## 37               3.751351   2.9589340
## 38               3.831074   0.9396843
## 39              12.702379   3.5977513
## 40               1.052567   1.5200933
## 41               4.625364   4.4753235
## 42               0.814180   0.9825837
## 43               6.346105   3.4509357
## 44              25.145561   3.2013603
## 45               2.763885   0.7959810
```

```
## 46                       0.625741  0.3196211
## 47                       8.001024  3.1246001
## 48                       6.724540  1.3829942
## 49                       1.852994  1.4571013
## 50                       5.686986  1.7056487
## 51                       0.563626  0.8871131
```

2. If `rank(x)` gives you the ranks of `x` from lowest to highest, `rank(-x)` gives you the ranks from highest to lowest. Use the function `mutate` to add a column `rank` containing the rank, from highest to lowest murder rate. Make sure you redefine murders so we can keep using this variable.

```
murders <- mutate(murders, rank = rank(murders$rate))
murders
```

```
##                    state abb      region population total
## 1                Alabama  AL       South    4779736   135
## 2                 Alaska  AK        West     710231    19
## 3                Arizona  AZ        West    6392017   232
## 4               Arkansas  AR       South    2915918    93
## 5             California  CA        West   37253956  1257
## 6               Colorado  CO        West    5029196    65
## 7            Connecticut  CT   Northeast    3574097    97
## 8               Delaware  DE       South     897934    38
## 9   District of Columbia  DC       South     601723    99
## 10               Florida  FL       South   19687653   669
## 11               Georgia  GA       South    9920000   376
## 12                Hawaii  HI        West    1360301     7
## 13                 Idaho  ID        West    1567582    12
## 14              Illinois  IL North Central   12830632   364
## 15               Indiana  IN North Central    6483802   142
## 16                  Iowa  IA North Central    3046355    21
## 17                Kansas  KS North Central    2853118    63
## 18              Kentucky  KY       South    4339367   116
## 19             Louisiana  LA       South    4533372   351
## 20                 Maine  ME   Northeast    1328361    11
## 21              Maryland  MD       South    5773552   293
## 22         Massachusetts  MA   Northeast    6547629   118
## 23              Michigan  MI North Central    9883640   413
## 24             Minnesota  MN North Central    5303925    53
## 25           Mississippi  MS       South    2967297   120
## 26              Missouri  MO North Central    5988927   321
## 27               Montana  MT        West     989415    12
## 28              Nebraska  NE North Central    1826341    32
## 29                Nevada  NV        West    2700551    84
## 30         New Hampshire  NH   Northeast    1316470     5
## 31            New Jersey  NJ   Northeast    8791894   246
## 32            New Mexico  NM        West    2059179    67
## 33              New York  NY   Northeast   19378102   517
## 34        North Carolina  NC       South    9535483   286
## 35          North Dakota  ND North Central     672591     4
## 36                  Ohio  OH North Central   11536504   310
## 37              Oklahoma  OK       South    3751351   111
## 38                Oregon  OR        West    3831074    36
```

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```
## 39       Pennsylvania  PA     Northeast   12702379  457
## 40       Rhode Island  RI     Northeast    1052567   16
## 41     South Carolina  SC         South    4625364  207
## 42       South Dakota  SD North Central     814180    8
## 43          Tennessee  TN         South    6346105  219
## 44              Texas  TX         South   25145561  805
## 45               Utah  UT          West    2763885   22
## 46            Vermont  VT     Northeast     625741    2
## 47           Virginia  VA         South    8001024  250
## 48         Washington  WA          West    6724540   93
## 49      West Virginia  WV         South    1852994   27
## 50          Wisconsin  WI North Central    5686986   97
## 51            Wyoming  WY          West     563626    5
##    population_in_millions       rate rank
## 1                4.779736  2.8244238   29
## 2                0.710231  2.6751860   25
## 3                6.392017  3.6295273   42
## 4                2.915918  3.1893901   35
## 5               37.253956  3.3741383   38
## 6                5.029196  1.2924531   14
## 7                3.574097  2.7139722   27
## 8                0.897934  4.2319369   46
## 9                0.601723 16.4527532   51
## 10              19.687653  3.3980688   39
## 11               9.920000  3.7903226   43
## 12               1.360301  0.5145920    3
## 13               1.567582  0.7655102    6
## 14              12.830632  2.8369608   30
## 15               6.483802  2.1900730   21
## 16               3.046355  0.6893484    5
## 17               2.853118  2.2081106   22
## 18               4.339367  2.6732010   24
## 19               4.533372  7.7425810   50
## 20               1.328361  0.8280881    8
## 21               5.773552  5.0748655   48
## 22               6.547629  1.8021791   20
## 23               9.883640  4.1786225   45
## 24               5.303925  0.9992600   12
## 25               2.967297  4.0440846   44
## 26               5.988927  5.3598917   49
## 27               0.989415  1.2128379   13
## 28               1.826341  1.7521372   19
## 29               2.700551  3.1104763   33
## 30               1.316470  0.3798036    2
## 31               8.791894  2.7980319   28
## 32               2.059179  3.2537239   37
## 33              19.378102  2.6679599   23
## 34               9.535483  2.9993237   32
## 35               0.672591  0.5947151    4
## 36              11.536504  2.6871225   26
## 37               3.751351  2.9589340   31
## 38               3.831074  0.9396843   10
## 39              12.702379  3.5977513   41
## 40               1.052567  1.5200933   17
```

```
## 41                  4.625364  4.4753235   47
## 42                  0.814180  0.9825837   11
## 43                  6.346105  3.4509357   40
## 44                 25.145561  3.2013603   36
## 45                  2.763885  0.7959810    7
## 46                  0.625741  0.3196211    1
## 47                  8.001024  3.1246001   34
## 48                  6.724540  1.3829942   15
## 49                  1.852994  1.4571013   16
## 50                  5.686986  1.7056487   18
## 51                  0.563626  0.8871131    9
```

3. With dplyr, we can use `select` to show only certain columns. For example, with this code we would only show the states and population sizes:

```
select(murders, state, population) %>% head()
```

```
##          state population
## 1     Alabama    4779736
## 2      Alaska     710231
## 3     Arizona    6392017
## 4    Arkansas    2915918
## 5  California   37253956
## 6    Colorado    5029196
```

Use `select` to show the state names and abbreviations in `murders`. Do not redefine `murders`, just show the results.

```
select(murders, state, abb) %>% head()
```

```
##          state abb
## 1     Alabama  AL
## 2      Alaska  AK
## 3     Arizona  AZ
## 4    Arkansas  AR
## 5  California  CA
## 6    Colorado  CO
```

4. The **dplyr** function `filter` is used to choose specific rows of the data frame to keep. Unlike `select` which is for columns, `filter` is for rows. For example, you can show just the New York row like this:

```
filter(murders, state == "New York")
```

```
##      state abb    region population total population_in_millions    rate rank
## 1 New York  NY Northeast   19378102   517                 19.3781 2.66796   23
```

You can use other logical vectors to filter rows.

Use `filter` to show the top 5 states with the highest murder rates. After we add murder rate and rank, do not change the murders dataset, just show the result. Remember that you can filter based on the `rank` column.

```
filter(murders, rank < 6)
```

```
##            state abb       region population total population_in_millions
## 1        Hawaii  HI         West    1360301     7               1.360301
## 2          Iowa  IA North Central  3046355    21               3.046355
## 3 New Hampshire  NH    Northeast    1316470     5               1.316470
## 4  North Dakota  ND North Central   672591     4               0.672591
## 5       Vermont  VT    Northeast     625741     2               0.625741
##       rate rank
## 1 0.5145920    3
## 2 0.6893484    5
## 3 0.3798036    2
## 4 0.5947151    4
## 5 0.3196211    1
```

5. We can remove rows using the != operator. For example, to remove Florida, we would do this:

```
no_florida <- filter(murders, state != "Florida")
```

Create a new data frame called no_south that removes states from the South region. How many states are in this category? You can use the function **nrow** for this.

```
no_south <- filter(murders, region != 'South')
no_south
```

```
##            state abb       region population total population_in_millions
## 1        Alaska  AK         West     710231    19               0.710231
## 2       Arizona  AZ         West    6392017   232               6.392017
## 3    California  CA         West   37253956  1257              37.253956
## 4      Colorado  CO         West    5029196    65               5.029196
## 5   Connecticut  CT    Northeast    3574097    97               3.574097
## 6        Hawaii  HI         West    1360301     7               1.360301
## 7         Idaho  ID         West    1567582    12               1.567582
## 8      Illinois  IL North Central 12830632   364              12.830632
## 9       Indiana  IN North Central  6483802   142               6.483802
## 10         Iowa  IA North Central  3046355    21               3.046355
## 11       Kansas  KS North Central  2853118    63               2.853118
## 12        Maine  ME    Northeast    1328361    11               1.328361
## 13 Massachusetts MA    Northeast    6547629   118               6.547629
## 14     Michigan  MI North Central  9883640   413               9.883640
## 15    Minnesota  MN North Central  5303925    53               5.303925
## 16     Missouri  MO North Central  5988927   321               5.988927
## 17      Montana  MT         West     989415    12               0.989415
## 18     Nebraska  NE North Central  1826341    32               1.826341
## 19       Nevada  NV         West    2700551    84               2.700551
## 20 New Hampshire NH    Northeast    1316470     5               1.316470
## 21    New Jersey NJ    Northeast    8791894   246               8.791894
## 22    New Mexico NM         West    2059179    67               2.059179
## 23      New York NY    Northeast   19378102   517              19.378102
## 24  North Dakota ND North Central   672591     4               0.672591
## 25         Ohio  OH North Central 11536504   310              11.536504
## 26       Oregon  OR         West    3831074    36               3.831074
```

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```
## 27   Pennsylvania  PA     Northeast  12702379  457               12.702379
## 28   Rhode Island  RI     Northeast   1052567   16                1.052567
## 29   South Dakota  SD North Central    814180    8                0.814180
## 30           Utah  UT         West    2763885   22                2.763885
## 31        Vermont  VT     Northeast    625741    2                0.625741
## 32     Washington  WA         West    6724540   93                6.724540
## 33      Wisconsin  WI North Central   5686986   97                5.686986
## 34        Wyoming  WY         West     563626    5                0.563626
##         rate rank
## 1  2.6751860   25
## 2  3.6295273   42
## 3  3.3741383   38
## 4  1.2924531   14
## 5  2.7139722   27
## 6  0.5145920    3
## 7  0.7655102    6
## 8  2.8369608   30
## 9  2.1900730   21
## 10 0.6893484    5
## 11 2.2081106   22
## 12 0.8280881    8
## 13 1.8021791   20
## 14 4.1786225   45
## 15 0.9992600   12
## 16 5.3598917   49
## 17 1.2128379   13
## 18 1.7521372   19
## 19 3.1104763   33
## 20 0.3798036    2
## 21 2.7980319   28
## 22 3.2537239   37
## 23 2.6679599   23
## 24 0.5947151    4
## 25 2.6871225   26
## 26 0.9396843   10
## 27 3.5977513   41
## 28 1.5200933   17
## 29 0.9825837   11
## 30 0.7959810    7
## 31 0.3196211    1
## 32 1.3829942   15
## 33 1.7056487   18
## 34 0.8871131    9
```

```
nrow(no_south)
```

```
## [1] 34
```

6. We can also use `%in%` to filter with **dplyr**. You can therefore see the data from New York and Texas like this:

```
filter(murders, state %in% c("New York", "Texas"))
```

```
##       state abb   region population total population_in_millions   rate rank
## 1 New York  NY Northeast   19378102   517               19.37810 2.66796   23
## 2    Texas  TX     South   25145561   805               25.14556 3.20136   36
```

Create a new data frame called `murders_nw` with only the states from the Northeast and the West. How many states are in this category?

```
murders_nw <- filter(murders, region %in% c("Northest", "West"))
murders_nw
```

```
##          state abb region population total population_in_millions      rate rank
## 1       Alaska  AK   West     710231    19               0.710231 2.6751860   25
## 2      Arizona  AZ   West    6392017   232               6.392017 3.6295273   42
## 3   California  CA   West   37253956  1257              37.253956 3.3741383   38
## 4     Colorado  CO   West    5029196    65               5.029196 1.2924531   14
## 5       Hawaii  HI   West    1360301     7               1.360301 0.5145920    3
## 6        Idaho  ID   West    1567582    12               1.567582 0.7655102    6
## 7      Montana  MT   West     989415    12               0.989415 1.2128379   13
## 8       Nevada  NV   West    2700551    84               2.700551 3.1104763   33
## 9   New Mexico  NM   West    2059179    67               2.059179 3.2537239   37
## 10      Oregon  OR   West    3831074    36               3.831074 0.9396843   10
## 11        Utah  UT   West    2763885    22               2.763885 0.7959810    7
## 12  Washington  WA   West    6724540    93               6.724540 1.3829942   15
## 13     Wyoming  WY   West     563626     5               0.563626 0.8871131    9
```

7. Suppose you want to live in the Northeast or West **and** want the murder rate to be less than 1. We want to see the data for the states satisfying these options. Note that you can use logical operators with `filter`. Here is an example in which we filter to keep only small states in the Northeast region.

```
filter(murders, population < 5000000 & region == "Northeast")
```

```
##            state abb    region population total population_in_millions      rate
## 1    Connecticut  CT Northeast    3574097    97               3.574097 2.7139722
## 2          Maine  ME Northeast    1328361    11               1.328361 0.8280881
## 3  New Hampshire  NH Northeast    1316470     5               1.316470 0.3798036
## 4   Rhode Island  RI Northeast    1052567    16               1.052567 1.5200933
## 5        Vermont  VT Northeast     625741     2               0.625741 0.3196211
##   rank
## 1   27
## 2    8
## 3    2
## 4   17
## 5    1
```

Make sure `murders` has been defined with `rate` and `rank` and still has all states. Create a table called `my_states` that contains rows for states satisfying both the conditions: it is in the Northeast or West and the murder rate is less than 1. Use select to show only the state name, the rate, and the rank.

```
my_states <- filter(murders, region %in% c("Northeast", "West") & rate <1)
my_states
```

```
##           state abb   region population total population_in_millions      rate
## 1        Hawaii  HI     West    1360301     7               1.360301 0.5145920
## 2         Idaho  ID     West    1567582    12               1.567582 0.7655102
## 3         Maine  ME Northeast    1328361    11               1.328361 0.8280881
## 4 New Hampshire  NH Northeast    1316470     5               1.316470 0.3798036
## 5        Oregon  OR     West    3831074    36               3.831074 0.9396843
## 6          Utah  UT     West    2763885    22               2.763885 0.7959810
## 7       Vermont  VT Northeast     625741     2               0.625741 0.3196211
## 8       Wyoming  WY     West     563626     5               0.563626 0.8871131
##   rank
## 1    3
## 2    6
## 3    8
## 4    2
## 5   10
## 6    7
## 7    1
## 8    9
```

```
select(my_states, state, rate, rank)
```

```
##           state      rate rank
## 1        Hawaii 0.5145920    3
## 2         Idaho 0.7655102    6
## 3         Maine 0.8280881    8
## 4 New Hampshire 0.3798036    2
## 5        Oregon 0.9396843   10
## 6          Utah 0.7959810    7
## 7       Vermont 0.3196211    1
## 8       Wyoming 0.8871131    9
```

4.5 The pipe: %>%

With **dplyr** we can perform a series of operations, for example `select` and then `filter`, by sending the results of one function to another using what is called the *pipe* operator: `%>%`. Some details are included below.

We wrote code above to show three variables (state, region, rate) for states that have murder rates below 0.71. To do this, we defined the intermediate object `new_table`. In **dplyr** we can write code that looks more like a description of what we want to do without intermediate objects:

$$original\ data \rightarrow select \rightarrow filter$$

For such an operation, we can use the pipe `%>%`. The code looks like this:

```
murders %>% select(state, region, rate) %>% filter(rate <= 0.71)
```

```
##           state        region      rate
## 1        Hawaii          West 0.5145920
## 2          Iowa North Central 0.6893484
## 3 New Hampshire      Northeast 0.3798036
## 4  North Dakota North Central 0.5947151
## 5       Vermont      Northeast 0.3196211
```

```
#>           state        region  rate
#> 1        Hawaii          West 0.515
#> 2          Iowa North Central 0.689
#> 3 New Hampshire      Northeast 0.380
#> 4  North Dakota North Central 0.595
#> 5       Vermont      Northeast 0.320
```

This line of code is equivalent to the two lines of code above. What is going on here?

In general, the pipe sends the result of the left side of the pipe to be the first argument of the function on the right side of the pipe. Here is a very simple example:

```
16 %>% sqrt()
```

```
## [1] 4
```

We can continue to pipe values along:

```
16 %>% sqrt() %>% log2()
```

```
## [1] 2
```

The above statement is equivalent to `log2(sqrt(16))`.

Remember that the pipe sends values to the first argument, so we can define other arguments as if the first argument is already defined:

```
16 %>% sqrt() %>% log(base = 2)
```

```
## [1] 2
```

Therefore, when using the pipe with data frames and **dplyr**, we no longer need to specify the required first argument since the **dplyr** functions we have described all take the data as the first argument. In the code we wrote:

```
murders %>% select(state, region, rate) %>% filter(rate <= 0.71)
```

```
##           state        region      rate
## 1        Hawaii          West 0.5145920
## 2          Iowa North Central 0.6893484
## 3 New Hampshire      Northeast 0.3798036
## 4  North Dakota North Central 0.5947151
## 5       Vermont      Northeast 0.3196211
```

`murders` is the first argument of the `select` function, and the new data frame (formerly `new_table`) is the first argument of the `filter` function.

Note that the pipe works well with functions where the first argument is the input data. Functions in **tidyverse** packages like **dplyr** have this format and can be used easily with the pipe.

4.6 Exercises

1. The pipe `%>%` can be used to perform operations sequentially without having to define intermediate objects. Start by redefining murder to include rate and rank.

```
murders <- mutate(murders, rate =  total / population * 100000,
                  rank = rank(-rate))
```

In the solution to the previous exercise, we did the following:

```
my_states <- filter(murders, region %in% c("Northeast", "West") &
                    rate < 1)

select(my_states, state, rate, rank)
```

```
##             state      rate rank
## 1          Hawaii 0.5145920   49
## 2           Idaho 0.7655102   46
## 3           Maine 0.8280881   44
## 4 New Hampshire 0.3798036     50
## 5          Oregon 0.9396843   42
## 6            Utah 0.7959810   45
## 7         Vermont 0.3196211   51
## 8         Wyoming 0.8871131   43
```

The pipe `%>%` permits us to perform both operations sequentially without having to define an intermediate variable `my_states`. We therefore could have mutated and selected in the same line like this:

```
mutate(murders, rate =  total / population * 100000,
       rank = rank(-rate)) %>% select(state, rate, rank)
```

```
##                     state      rate rank
## 1                 Alabama  2.8244238   23
## 2                  Alaska  2.6751860   27
## 3                 Arizona  3.6295273   10
## 4                Arkansas  3.1893901   17
## 5              California  3.3741383   14
## 6                Colorado  1.2924531   38
## 7             Connecticut  2.7139722   25
## 8                Delaware  4.2319369    6
## 9    District of Columbia 16.4527532    1
## 10                Florida  3.3980688   13
## 11                Georgia  3.7903226    9
## 12                 Hawaii  0.5145920   49
## 13                  Idaho  0.7655102   46
## 14               Illinois  2.8369608   22
## 15                Indiana  2.1900730   31
## 16                   Iowa  0.6893484   47
## 17                 Kansas  2.2081106   30
## 18               Kentucky  2.6732010   28
## 19              Louisiana  7.7425810    2
## 20                  Maine  0.8280881   44
```

```
## 21                Maryland  5.0748655    4
## 22           Massachusetts  1.8021791   32
## 23                Michigan  4.1786225    7
## 24               Minnesota  0.9992600   40
## 25             Mississippi  4.0440846    8
## 26                Missouri  5.3598917    3
## 27                 Montana  1.2128379   39
## 28                Nebraska  1.7521372   33
## 29                  Nevada  3.1104763   19
## 30           New Hampshire  0.3798036   50
## 31              New Jersey  2.7980319   24
## 32              New Mexico  3.2537239   15
## 33                New York  2.6679599   29
## 34          North Carolina  2.9993237   20
## 35            North Dakota  0.5947151   48
## 36                    Ohio  2.6871225   26
## 37                Oklahoma  2.9589340   21
## 38                  Oregon  0.9396843   42
## 39            Pennsylvania  3.5977513   11
## 40            Rhode Island  1.5200933   35
## 41          South Carolina  4.4753235    5
## 42            South Dakota  0.9825837   41
## 43               Tennessee  3.4509357   12
## 44                   Texas  3.2013603   16
## 45                    Utah  0.7959810   45
## 46                 Vermont  0.3196211   51
## 47                Virginia  3.1246001   18
## 48              Washington  1.3829942   37
## 49           West Virginia  1.4571013   36
## 50               Wisconsin  1.7056487   34
## 51                 Wyoming  0.8871131   43
```

Notice that `select` no longer has a data frame as the first argument. The first argument is assumed to be the result of the operation conducted right before the %>%.

Repeat the previous exercise, but now instead of creating a new object, show the result and only include the state, rate, and rank columns. Use a pipe %>% to do this in just one line.

```
mutate(murders, rate =  total / population * 100000, rank = rank(rate)) %>%
  filter(region %in% c("Northeast", "West") & rate < 1) %>%
  select(state, rate, rank, region)
```

```
##             state      rate rank    region
## 1          Hawaii 0.5145920    3      West
## 2           Idaho 0.7655102    6      West
## 3           Maine 0.8280881    8 Northeast
## 4 New Hampshire 0.3798036      2 Northeast
## 5          Oregon 0.9396843   10      West
## 6            Utah 0.7959810    7      West
## 7         Vermont 0.3196211    1 Northeast
## 8         Wyoming 0.8871131    9      West
```

2. Reset `murders` to the original table by using `data(murders)`. Use a pipe to create a new data frame called `my_states` that considers only states in the Northeast or West which have a murder rate lower

than 1, and contains only the state, rate and rank columns. The pipe should also have four components separated by three %>%. The code should look something like this:

```
#my_states <- murders %>%
 # mutate SOMETHING %>%
 # filter SOMETHING %>%
 # select SOMETHING
```

```
data(murders)
my_state <- murders %>%
  mutate (rate =  total / population * 100000, rank = rank(-rate)) %>%
  filter (region %in% c("Northeast", "West") & rate < 1) %>%
  select (state, rate, rank)

my_state
```

```
##             state      rate rank
## 1          Hawaii 0.5145920   49
## 2           Idaho 0.7655102   46
## 3           Maine 0.8280881   44
## 4 New Hampshire 0.3798036   50
## 5          Oregon 0.9396843   42
## 6            Utah 0.7959810   45
## 7         Vermont 0.3196211   51
## 8         Wyoming 0.8871131   43
```