Starting with data

Data Carpentry contributors

Learning Objectives

- Describe what a data frame is.
- Load external data from a .csv file into a data frame.
- Summarize the contents of a data frame.
- Describe what a factor is.
- Convert between strings and factors.
- Reorder and rename factors.
- Change how character strings are handled in a data frame.
- Format dates.

Presentation of the Survey Data

We are studying the species repartition and weight of animals caught in plots in our study area. The dataset is stored as a comma separated value (CSV) file. Each row holds information for a single animal, and the columns represent:

Column	Description
record_id	Unique id for the observation
month	month of observation
day	day of observation
year	year of observation
plot_id	ID of a particular plot
species_id	2-letter code
sex	sex of animal ("M", "F")
hindfoot_length	length of the hindfoot in mm
weight	weight of the animal in grams
genus	genus of animal
species	species of animal
taxon	e.g. Rodent, Reptile, Bird, Rabbit
plot_type	type of plot

We are going to use the R function `download.file()` to download the CSV file that contains the survey data from figshare, and we will use `read.csv()` to load into memory the content of the CSV file as an object of class `data.frame`.

```
download.file("https://bit.ly/2JF82e0", destfile = "./portal_data_joined.csv")
```

You are now ready to load the data:

```
surveys <- read.csv("portal_data_joined.csv")
```

This statement doesn't produce any output because, as you might recall, assignments don't display anything. If we want to check that our data has been loaded, we can see the contents of the data frame by typing its name: `surveys`.

Wow… that was a lot of output. At least it means the data loaded properly. Let's check the top (the first 6 lines) of this data frame using the function `head()`:

```
head(surveys)
```

```
##   record_id month day year plot_id species_id sex hindfoot_length weight
## 1         1     7  16 1977       2         NL   M              32     NA
## 2        72     8  19 1977       2         NL   M              31     NA
## 3       224     9  13 1977       2         NL                  NA     NA
## 4       266    10  16 1977       2         NL                  NA     NA
## 5       349    11  12 1977       2         NL                  NA     NA
## 6       363    11  12 1977       2         NL                  NA     NA
##     genus  species   taxa plot_type
## 1 Neotoma albigula Rodent   Control
## 2 Neotoma albigula Rodent   Control
## 3 Neotoma albigula Rodent   Control
## 4 Neotoma albigula Rodent   Control
## 5 Neotoma albigula Rodent   Control
## 6 Neotoma albigula Rodent   Control
```

```
## Try also
## View(surveys)
```

> **Note**
>
> `read.csv` assumes that fields are delineated by commas, however, in several countries, the comma is used as a decimal separator and the semicolon (;) is used as a field delineator. If you want to read in this type of files in R, you can use the `read.csv2` function. It behaves exactly like `read.csv` but uses different parameters for the decimal and the field separators. If you are working with another format, they can be both specified by the user. Check out the help for `read.csv()` by typing `?read.csv` to learn more. There is also the `read.delim()` for in tab separated data files. It is important to note that all of these functions are actually wrapper functions for the main `read.table()` function with different arguments. As such, the surveys data above could have also been loaded by using `read.table()` with the separation argument as `,`. The code is as follows: `surveys <- read.table(file="data/portal_data_joined.csv", sep=",", header=TRUE)`. The header argument has to be set to TRUE to be able to read the headers as by default `read.table()` has the header argument set to FALSE.

What are data frames?

Data frames are the *de facto* data structure for most tabular data, and what we use for statistics and plotting.

A data frame can be created by hand, but most commonly they are generated by the functions `read.csv()` or `read.table()`; in other words, when importing spreadsheets from your hard drive (or the web).

A data frame is the representation of data in the format of a table where the columns are vectors that all have the same length. Because columns are vectors, each column must contain a single type of data (e.g., characters, integers, factors). For example, here is a figure depicting a data frame comprising a numeric, a character, and a logical vector.

We can see this when inspecting the structure of a data frame with the function `str()`:

```
str(surveys)
```

```
## 'data.frame':    34786 obs. of  13 variables:
##  $ record_id      : int  1 72 224 266 349 363 435 506 588 661 ...
##  $ month          : int  7 8 9 10 11 11 12 1 2 3 ...
##  $ day            : int  16 19 13 16 12 12 10 8 18 11 ...
##  $ year           : int  1977 1977 1977 1977 1977 1977 1977 1978 1978 1978 ...
##  $ plot_id        : int  2 2 2 2 2 2 2 2 2 2 ...
##  $ species_id     : Factor w/ 48 levels "AB","AH","AS",..: 16 16 16 16 16 16 16 16 16 16 ...
##  $ sex            : Factor w/ 3 levels "","F","M": 3 3 1 1 1 1 1 3 1 ...
##  $ hindfoot_length: int  32 31 NA NA NA NA NA NA NA NA ...
##  $ weight         : int  NA NA NA NA NA NA NA NA 218 NA ...
##  $ genus          : Factor w/ 26 levels "Ammodramus","Ammospermophilus",..: 13 13 13 13 13 13 13 13 
##  $ species        : Factor w/ 40 levels "albigula","audubonii",..: 1 1 1 1 1 1 1 1 1 1 ...
##  $ taxa           : Factor w/ 4 levels "Bird","Rabbit",..: 4 4 4 4 4 4 4 4 4 4 ...
##  $ plot_type      : Factor w/ 5 levels "Control","Long-term Krat Exclosure",..: 1 1 1 1 1 1 1 1 1
```

Inspecting `data.frame` Objects

We already saw how the functions `head()` and `str()` can be useful to check the content and the structure of a data frame. Here is a non-exhaustive list of functions to get a sense of the content/structure of the data. Let's try them out!

- Size:
  - `dim(surveys)` - returns a vector with the number of rows in the first element, and the number of columns as the second element (the **dim**ensions of the object)
  - `nrow(surveys)` - returns the number of rows
  - `ncol(surveys)` - returns the number of columns
- Content:
  - `head(surveys)` - shows the first 6 rows
  - `tail(surveys)` - shows the last 6 rows
- Names:
  - `names(surveys)` - returns the column names (synonym of `colnames()` for `data.frame` objects)
  - `rownames(surveys)` - returns the row names
- Summary:
  - `str(surveys)` - structure of the object and information about the class, length and content of each column
  - `summary(surveys)` - summary statistics for each column

Note: most of these functions are "generic", they can be used on other types of objects besides `data.frame`.

> **Challenge**
>
> Based on the output of `str(surveys)`, can you answer the following questions?
>
> - What is the class of the object `surveys`?
> - How many rows and how many columns are in this object?
> - How many species have been recorded during these surveys?
>
> ```r
> str(surveys)
> ```
>
> ```
> ## 'data.frame':  34786 obs. of  13 variables:
> ##  $ record_id      : int  1 72 224 266 349 363 435 506 588 661 ...
> ##  $ month          : int  7 8 9 10 11 11 12 1 2 3 ...
> ##  $ day            : int  16 19 13 16 12 12 10 8 18 11 ...
> ##  $ year           : int  1977 1977 1977 1977 1977 1977 1977 1978 1978 1978 ...
> ##  $ plot_id        : int  2 2 2 2 2 2 2 2 2 2 ...
> ```

```
##  $ species_id     : Factor w/ 48 levels "AB","AH","AS",..: 16 16 16 16 16 16 16 16 16 16 ...
##  $ sex            : Factor w/ 3 levels "","F","M": 3 3 1 1 1 1 1 1 3 1 ...
##  $ hindfoot_length: int  32 31 NA NA NA NA NA NA NA NA ...
##  $ weight         : int  NA NA NA NA NA NA NA NA 218 NA ...
##  $ genus          : Factor w/ 26 levels "Ammodramus","Ammospermophilus",..: 13 13 13 13 13 13 13
##  $ species        : Factor w/ 40 levels "albigula","audubonii",..: 1 1 1 1 1 1 1 1 1 1 ...
##  $ taxa           : Factor w/ 4 levels "Bird","Rabbit",..: 4 4 4 4 4 4 4 4 4 4 ...
##  $ plot_type      : Factor w/ 5 levels "Control","Long-term Krat Exclosure",..: 1 1 1 1 1 1 1 1
```

```
## * class: data frame
## * how many rows: 34786,  how many columns: 13
## * how many species: 48
```

Indexing and subsetting data frames

Our survey data frame has rows and columns (it has 2 dimensions), if we want to extract some specific data from it, we need to specify the "coordinates" we want from it. Row numbers come first, followed by column numbers. However, note that different ways of specifying these coordinates lead to results with different classes.

```
# first element in the first column of the data frame (as a vector)
surveys[1, 1]
```

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

```
# first element in the 6th column (as a vector)
surveys[1, 6]
```

```
## [1] NL
## 48 Levels: AB AH AS BA CB CM CQ CS CT CU CV DM DO DS DX NL OL OT OX ... ZL
```

```
# first column of the data frame (as a vector)
#surveys[, 1]
# first column of the data frame (as a data.frame)
#surveys[1]
# first three elements in the 7th column (as a vector)
surveys[1:3, 7]
```

```
## [1] M M
## Levels:  F M
```

```
# the 3rd row of the data frame (as a data.frame)
surveys[3, ]
```

```
##   record_id month day year plot_id species_id sex hindfoot_length weight
## 3       224     9  13 1977       2         NL                  NA     NA
##     genus  species   taxa plot_type
## 3 Neotoma albigula Rodent   Control
```

```
# equivalent to head_surveys <- head(surveys)
head_surveys <- surveys[1:6, ]
```

`:` is a special function that creates numeric vectors of integers in increasing or decreasing order, test `1:10` and `10:1` for instance.

You can also exclude certain indices of a data frame using the "`-`" sign:

```r
#surveys[, -1]          # The whole data frame, except the first column
surveys[-c(7:34786), ] # Equivalent to head(surveys)
```

```
##   record_id month day year plot_id species_id sex hindfoot_length weight
## 1         1     7  16 1977       2         NL   M              32     NA
## 2        72     8  19 1977       2         NL   M              31     NA
## 3       224     9  13 1977       2         NL                  NA     NA
## 4       266    10  16 1977       2         NL                  NA     NA
## 5       349    11  12 1977       2         NL                  NA     NA
## 6       363    11  12 1977       2         NL                  NA     NA
##     genus  species   taxa plot_type
## 1 Neotoma albigula Rodent   Control
## 2 Neotoma albigula Rodent   Control
## 3 Neotoma albigula Rodent   Control
## 4 Neotoma albigula Rodent   Control
## 5 Neotoma albigula Rodent   Control
## 6 Neotoma albigula Rodent   Control
```

Data frames can be subset by calling indices (as shown previously), but also by calling their column names directly:

```r
#surveys["species_id"]       # Result is a data.frame
#surveys[, "species_id"]     # Result is a vector
#surveys[["species_id"]]     # Result is a vector
#surveys$species_id          # Result is a vector
```

In RStudio, you can use the autocompletion feature to get the full and correct names of the columns.

Challenge

1. Create a `data.frame` (`surveys_200`) containing only the data in row 200 of the `surveys` dataset.
2. Notice how `nrow()` gave you the number of rows in a `data.frame`?
   - Use that number to pull out just that last row in the data frame.
   - Compare that with what you see as the last row using `tail()` to make sure it's meeting expectations.
   - Pull out that last row using `nrow()` instead of the row number.
   - Create a new data frame (`surveys_last`) from that last row.
3. Use `nrow()` to extract the row that is in the middle of the data frame. Store the content of this row in an object named `surveys_middle`.
4. Combine `nrow()` with the `-` notation above to reproduce the behavior of `head(surveys)`, keeping just the first through 6th rows of the surveys dataset.

```r
## 1.
surveys_200 <- surveys[200, ]
## 2.
# Saving `n_rows` to improve readability and reduce duplication
n_rows <- nrow(surveys)
surveys_last <- surveys[n_rows, ]
## 3.
surveys_middle <- surveys[n_rows / 2, ]
## 4.
surveys_head <- surveys[-(7:n_rows), ]
```

Factors

When we did `str(surveys)` we saw that several of the columns consist of integers. The columns `genus`, `species`, `sex`, `plot_type`, … however, are of a special class called `factor`. Factors are very useful and actually contribute to making R particularly well suited to working with data. So we are going to spend a little time introducing them.

Factors represent categorical data. They are stored as integers associated with labels and they can be ordered or unordered. While factors look (and often behave) like character vectors, they are actually treated as integer vectors by R. So you need to be very careful when treating them as strings.

Once created, factors can only contain a pre-defined set of values, known as *levels*. By default, R always sorts levels in alphabetical order. For instance, if you have a factor with 2 levels:

```
sex <- factor(c("male", "female", "female", "male"))
```

R will assign `1` to the level `"female"` and `2` to the level `"male"` (because `f` comes before `m`, even though the first element in this vector is `"male"`). You can see this by using the function `levels()` and you can find the number of levels using `nlevels()`:

```
levels(sex)
```

```
## [1] "female" "male"
```

```
nlevels(sex)
```

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

Sometimes, the order of the factors does not matter, other times you might want to specify the order because it is meaningful (e.g., "low", "medium", "high"), it improves your visualization, or it is required by a particular type of analysis. Here, one way to reorder our levels in the `sex` vector would be:

```
sex # current order
```

```
## [1] male   female female male
## Levels: female male
```

```
sex <- factor(sex, levels = c("male", "female"))
sex # after re-ordering
```

```
## [1] male   female female male
## Levels: male female
```

In R's memory, these factors are represented by integers (1, 2, 3), but are more informative than integers because factors are self describing: `"female"`, `"male"` is more descriptive than `1`, `2`. Which one is "male"? You wouldn't be able to tell just from the integer data. Factors, on the other hand, have this information built in. It is particularly helpful when there are many levels (like the species names in our example dataset).

Converting factors

If you need to convert a factor to a character vector, you use `as.character(x)`.

```
as.character(sex)
```

```
## [1] "male"   "female" "female" "male"
```

Converting factors where the levels appear as numbers (such as concentration levels, or years) to a numeric vector is a little trickier. The `as.numeric()` function returns the index values of the factor, not its levels, so it will result in an entirely new (and unwanted in this case) set of numbers. One method to avoid this is to convert factors to characters, and then to numbers.
Another method is to use the `levels()` function. Compare:

```r
year_fct <- factor(c(1990, 1983, 1977, 1998, 1990))
as.numeric(year_fct)               # Wrong! And there is no warning...
```

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

```r
as.numeric(as.character(year_fct)) # Works...
```

```
## [1] 1990 1983 1977 1998 1990
```

```r
as.numeric(levels(year_fct))[year_fct]    # The recommended way.
```

```
## [1] 1990 1983 1977 1998 1990
```

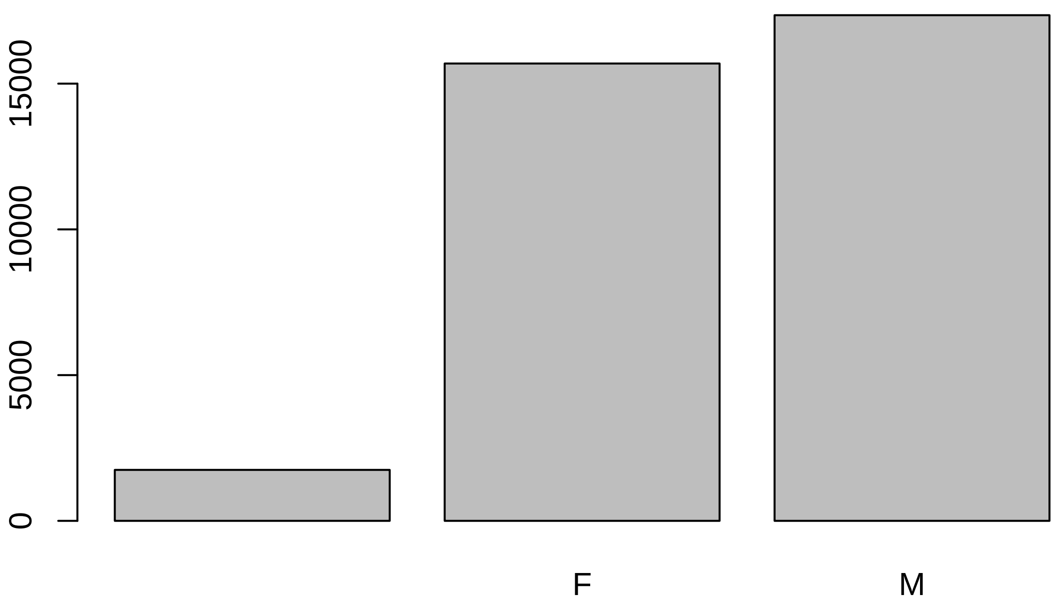
Notice that in the `levels()` approach, three important steps occur:

- We obtain all the factor levels using `levels(year_fct)`
- We convert these levels to numeric values using `as.numeric(levels(year_fct))`
- We then access these numeric values using the underlying integers of the vector `year_fct` inside the square brackets

Renaming factors

When your data is stored as a factor, you can use the `plot()` function to get a quick glance at the number of observations represented by each factor level. Let's look at the number of males and females captured over the course of the experiment:

```r
## bar plot of the number of females and males captured during the experiment:
plot(surveys$sex)
```



In addition to males and females, there are about 1700 individuals for which the sex information hasn't been recorded. Additionally, for these individuals, there is no label to indicate that the information is missing or undetermined. Let's rename this label to something more meaningful. Before doing that, we're going to pull out the data on sex and work with that data, so we're not modifying the working copy of the data frame:

```r
sex <- surveys$sex
head(sex)
```

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

```
## Levels:  F M
```

```
levels(sex)
```

```
## [1] ""  "F" "M"
```

```
levels(sex)[1] <- "undetermined"
levels(sex)
```

```
## [1] "undetermined" "F"            "M"
```

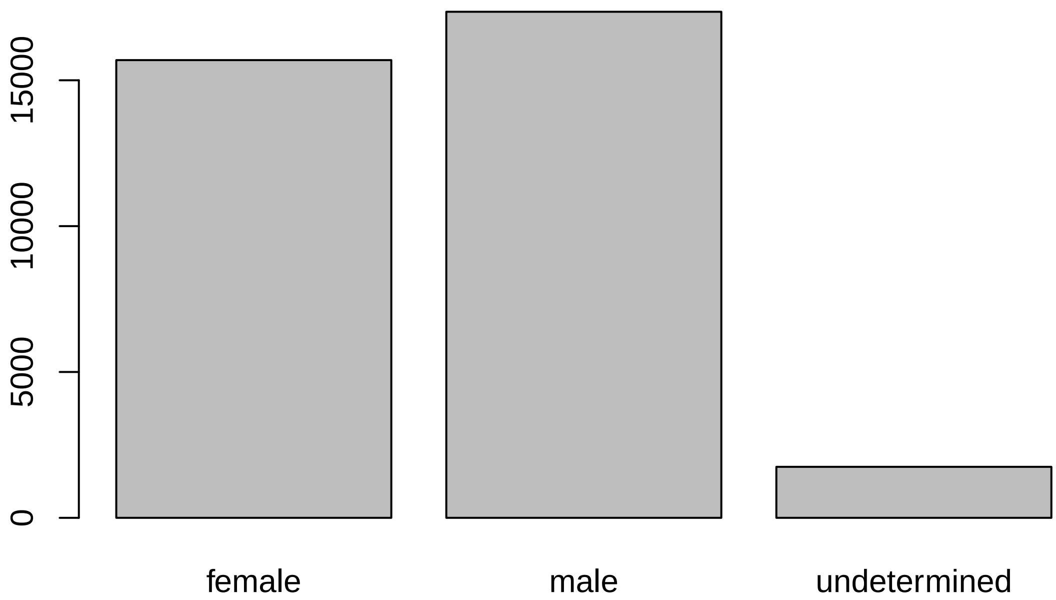
```
head(sex)
```

```
## [1] M            M            undetermined undetermined undetermined
## [6] undetermined
## Levels: undetermined F M
```

Challenge

- Rename "F" and "M" to "female" and "male" respectively.
- Now that we have renamed the factor level to "undetermined", can you recreate the barplot such that "undetermined" is last (after "male")?

```
levels(sex)[2:3] <- c("female", "male")
sex <- factor(sex, levels = c("female", "male", "undetermined"))
plot(sex)
```



Using `stringsAsFactors=FALSE`

By default, when building or importing a data frame, the columns that contain characters (i.e. text) are coerced (= converted) into factors. Depending on what you want to do with the data, you may want to keep these columns as `character`. To do so, `read.csv()` and `read.table()` have an argument called `stringsAsFactors` which can be set to `FALSE`.

In most cases, it is preferable to set `stringsAsFactors = FALSE` when importing data and to convert as a factor only the columns that require this data type.

```
## Compare the difference between our data read as `factor` vs `character`.
surveys <- read.csv("data/portal_data_joined.csv", stringsAsFactors = TRUE)
str(surveys)
surveys <- read.csv("data/portal_data_joined.csv", stringsAsFactors = FALSE)
str(surveys)
## Convert the column "plot_type" into a factor
surveys$plot_type <- factor(surveys$plot_type)
```

Challenge

1. We have seen how data frames are created when using `read.csv()`, but they can also be created by hand with the `data.frame()` function. There are a few mistakes in this hand-crafted `data.frame`. Can you spot and fix them? Don't hesitate to experiment!

```
animal_data <- data.frame(
          animal = c(dog, cat, sea cucumber, sea urchin),
          feel = c("furry", "squishy", "spiny"),
          weight = c(45, 8 1.1, 0.8)
          )
```

2. Can you predict the class for each of the columns in the following example? Check your guesses using `str(country_climate)`:

   - Are they what you expected? Why? Why not?
   - What would have been different if we had added `stringsAsFactors = FALSE` when creating the data frame?
   - What would you need to change to ensure that each column had the accurate data type?

```
country_climate <- data.frame(
       country = c("Canada", "Panama", "South Africa", "Australia"),
       climate = c("cold", "hot", "temperate", "hot/temperate"),
       temperature = c(10, 30, 18, "15"),
       northern_hemisphere = c(TRUE, TRUE, FALSE, "FALSE"),
       has_kangaroo = c(FALSE, FALSE, FALSE, 1)
       )
```

The automatic conversion of data type is sometimes a blessing, sometimes an annoyance. Be aware that it exists, learn the rules, and double check that data you import in R are of the correct type within your data frame. If not, use it to your advantage to detect mistakes that might have been introduced during data entry (a letter in a column that should only contain numbers for instance).

Learn more in this RStudio tutorial

Formatting Dates

One of the most common issues that new (and experienced!) R users have is converting date and time information into a variable that is appropriate and usable during analyses. As a reminder from earlier in this lesson, the best practice for dealing with date data is to ensure that each component of your date is stored as a separate variable. Using `str()`, We can confirm that our data frame has a separate column for day, month, and year, and that each contains integer values.

```
str(surveys)
```

We are going to use the `ymd()` function from the package **`lubridate`** (which belongs to the **`tidyverse`**; learn more here). . **`lubridate`** gets installed as part as the **`tidyverse`** installation. When you load the **`tidyverse`** (`library(tidyverse)`), the core packages (the packages used in most data analyses) get loaded. **`lubridate`** however does not belong to the core tidyverse, so you have to load it explicitly with `library(lubridate)`

Start by loading the required package:

```
library(lubridate)
```

`ymd()` takes a vector representing year, month, and day, and converts it to a `Date` vector. `Date` is a class of data recognized by R as being a date and can be manipulated as such. The argument that the function requires is flexible, but, as a best practice, is a character vector formatted as “YYYY-MM-DD”.

Let’s create a date object and inspect the structure:

```
my_date <- ymd("2015-01-01")
str(my_date)
```

```
##  Date[1:1], format: "2015-01-01"
```

Now let’s paste the year, month, and day separately - we get the same result:

```
# sep indicates the character to use to separate each component
my_date <- ymd(paste("2015", "1", "1", sep = "-"))
str(my_date)
```

```
##  Date[1:1], format: "2015-01-01"
```

Now we apply this function to the surveys dataset. Create a character vector from the `year`, `month`, and `day` columns of `surveys` using `paste()`:

```
#paste(surveys$year, surveys$month, surveys$day, sep = "-")
```

This character vector can be used as the argument for `ymd()`:

```
#ymd(paste(surveys$year, surveys$month, surveys$day, sep = "-"))
```

The resulting `Date` vector can be added to `surveys` as a new column called `date`:

```
surveys$date <- ymd(paste(surveys$year, surveys$month, surveys$day, sep = "-"))
```

```
## Warning: 129 failed to parse.
```

```
str(surveys) # notice the new column, with 'date' as the class
```

```
## 'data.frame':    34786 obs. of  14 variables:
##  $ record_id      : int  1 72 224 266 349 363 435 506 588 661 ...
##  $ month          : int  7 8 9 10 11 11 12 1 2 3 ...
##  $ day            : int  16 19 13 16 12 12 10 8 18 11 ...
##  $ year           : int  1977 1977 1977 1977 1977 1977 1977 1978 1978 1978 ...
##  $ plot_id        : int  2 2 2 2 2 2 2 2 2 2 ...
##  $ species_id     : Factor w/ 48 levels "AB","AH","AS",..: 16 16 16 16 16 16 16 16 16 16 ...
##  $ sex            : Factor w/ 3 levels "","F","M": 3 3 1 1 1 1 1 1 3 1 ...
##  $ hindfoot_length: int  32 31 NA NA NA NA NA NA NA NA ...
##  $ weight         : int  NA NA NA NA NA NA NA NA 218 NA ...
##  $ genus          : Factor w/ 26 levels "Ammodramus","Ammospermophilus",..: 13 13 13 13 13 13 13 13 1
##  $ species        : Factor w/ 40 levels "albigula","audubonii",..: 1 1 1 1 1 1 1 1 1 1 ...
##  $ taxa           : Factor w/ 4 levels "Bird","Rabbit",..: 4 4 4 4 4 4 4 4 4 4 ...
##  $ plot_type      : Factor w/ 5 levels "Control","Long-term Krat Exclosure",..: 1 1 1 1 1 1 1 1 1 1
##  $ date           : Date, format: "1977-07-16" "1977-08-19" ...
```

Let’s make sure everything worked correctly. One way to inspect the new column is to use `summary()`:

```r
summary(surveys$date)
```

```
##         Min.      1st Qu.       Median         Mean      3rd Qu.
## "1977-07-16" "1984-03-12" "1990-07-22" "1990-12-15" "1997-07-29"
##         Max.         NA's
## "2002-12-31"        "129"
```

Something went wrong: some dates have missing values. Let's investigate where they are coming from.

We can use the functions we saw previously to deal with missing data to identify the rows in our data frame that are failing. If we combine them with what we learned about subsetting data frames earlier, we can extract the columns "year,"month",”day" from the records that have `NA` in our new column `date`. We will also use `head()` so we don't clutter the output:

```r
is_missing_date <- is.na(surveys$date)
date_columns <- c("year", "month", "day")
missing_dates <- surveys[is_missing_date,  date_columns]

head(missing_dates)
```

```
##      year month day
## 3144 2000     9  31
## 3817 2000     4  31
## 3818 2000     4  31
## 3819 2000     4  31
## 3820 2000     4  31
## 3856 2000     9  31
```

Why did these dates fail to parse? If you had to use these data for your analyses, how would you deal with this situation?