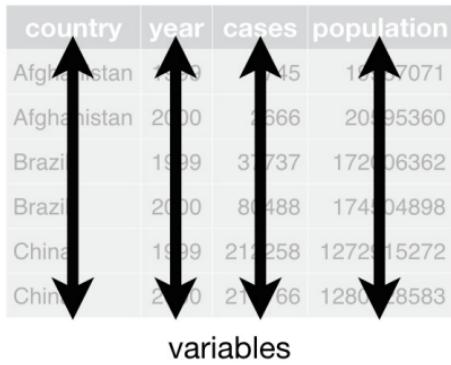




Tidy data

country	year	cases	population
Afghanistan	1990	745	19987071
Afghanistan	2000	2666	20595360
Brazil	1999	37737	172006362
Brazil	2000	80488	174504898
China	1999	21258	1272915272
China	2000	21766	128042583

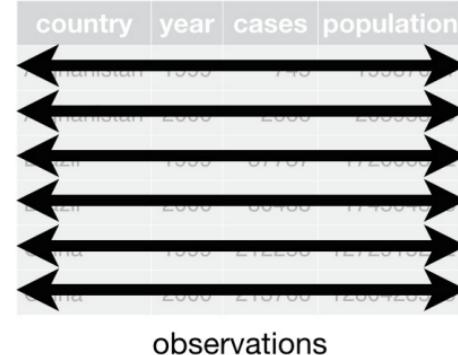
variables



This diagram illustrates the concept of 'variables' in a tidy dataset. It shows a table with four columns: country, year, cases, and population. Four vertical arrows point upwards from the bottom of each column to the column headers, indicating that each column represents a different variable.

country	year	cases	population
New Zealand	1999	745	19987071
New Zealand	2000	2666	20595360
Brazil	1999	37737	172006362
Brazil	2000	80488	174504898
China	1999	21258	1272915272
China	2000	21766	128042583

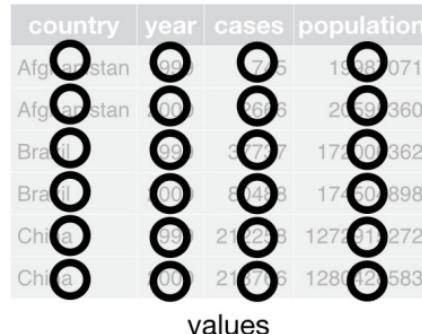
observations



This diagram illustrates the concept of 'observations' in a tidy dataset. It shows the same table as the first diagram, but with six rows instead of seven. Six horizontal arrows point downwards from the top of each row to the row itself, indicating that each row represents an observation.

country	year	cases	population
Afghanistan	99	745	19987071
Afghanistan	00	2666	20595360
Brazil	99	37737	172006362
Brazil	00	80488	174504898
China	99	21258	1272915272
China	00	21766	128042583

values



This diagram illustrates the concept of 'values' in a tidy dataset. It shows the same table as the previous diagrams, but with each data point represented by a small circle. The circles are arranged in a grid corresponding to the table's structure, with four columns (country, year, cases, population) and six rows (observations).

Tidy vs Untidy

Happy families are all alike; every unhappy family is unhappy in its own way
— Leo Tolstoy, Anna Karenina

```
## # A tibble: 317 × 7
##   artist      track    date.entered   wk1   wk2   wk3   wk4
##   <chr>      <chr>    <date>     <dbl> <dbl> <dbl> <dbl>
## 1 2 Pac     Baby Don't Cry (Keep... 2000-02-26     87     82     72     77
## 2 2Ge+her   The Hardest Part Of ... 2000-09-02     91     87     92     NA
## 3 3 Doors Down Kryptonite        2000-04-08     81     70     68     67
## 4 3 Doors Down Loser            2000-10-21     76     76     72     69
## 5 504 Boyz   Wobble Wobble       2000-04-15     57     34     25     17
## 6 98^0       Give Me Just One Nig... 2000-08-19     51     39     34     26
## 7 A*Teens    Dancing Queen       2000-07-08     97     97     96     95
## 8 Aaliyah   I Don't Wanna       2000-01-29     84     62     51     41
## 9 Aaliyah   Try Again          2000-03-18     59     53     38     28
## 10 Adams, Yolanda Open My Heart 2000-08-26     76     76     74     69
## # ... with 307 more rows
```



Modern data frames

Hadley Wickham / RStudio have a package that modifies data frames to be a bit more modern. The core features of tibbles is to have a nicer printing method as well as being "surly" and "lazy".

```
library(tibble)
```

```
iris
```

```
##      Sepal.Length Sepal.Width Petal.Length  
## 1          5.1       3.5        1.4  
## 2          4.9       3.0        1.4  
## 3          4.7       3.2        1.3  
## 4          4.6       3.1        1.5  
## 5          5.0       3.6        1.4  
## 6          5.4       3.9        1.7  
## 7          4.6       3.4        1.4  
## 8          5.0       3.4        1.5  
## 9          4.4       2.9        1.4  
## 10         4.9       3.1        1.5  
## 11         5.4       3.7        1.5  
## 12         4.8       3.4        1.6
```

```
(tbl_iris = as_tibble(iris))
```

```
## # A tibble: 150 × 5  
##   Sepal.Length Sepal.Width Petal.Length  
##       <dbl>       <dbl>       <dbl>  
## 1          5.1       3.5        1.4  
## 2          4.9       3.0        1.4  
## 3          4.7       3.2        1.3  
## 4          4.6       3.1        1.5  
## 5          5.0       3.6        1.4  
## 6          5.4       3.9        1.7  
## 7          4.6       3.4        1.4  
## 8          5.0       3.4        1.5  
## 9          4.4       2.9        1.4  
## 10         4.9       3.1        1.5  
## 11         5.4       3.7        1.5  
## 12         4.8       3.4        1.6
```

Tibbles are lazy

By default, subsetting tibbles always results in another tibble (\$ or [] can still be used to subset for a specific column).

```
tbl_iris[1,]
```

```
## # A tibble: 1 × 5
##   Sepal.Length Sepal.Width Petal.Length Petal.Width Species
##       <dbl>      <dbl>      <dbl>      <dbl> <fct>
## 1       5.1       3.5       1.4       0.2 setosa
```

```
tbl_iris[,1]
```

```
## # A tibble: 150 × 1
##   Sepal.Length
##       <dbl>
## 1       5.1
## 2       4.9
## 3       4.7
## 4       4.6
## 5       5
## 6       5.4
## 7       4.6
```

```
tbl_iris[[1]]
```

```
## [1] 5.1 4.9 4.7 4.6 5.0 5.4 4.6 5.0 4.4 4.9 5.4 4.
## [19] 5.7 5.1 5.4 5.1 4.6 5.1 4.8 5.0 5.0 5.2 5.2 4.
## [37] 5.5 4.9 4.4 5.1 5.0 4.5 4.4 5.0 5.1 4.8 5.1 4.
## [55] 6.5 5.7 6.3 4.9 6.6 5.2 5.0 5.9 6.0 6.1 5.6 6.
## [73] 6.3 6.1 6.4 6.6 6.8 6.7 6.0 5.7 5.5 5.5 5.8 6.
## [91] 5.5 6.1 5.8 5.0 5.6 5.7 5.7 6.2 5.1 5.7 6.3 5.
## [109] 6.7 7.2 6.5 6.4 6.8 5.7 5.8 6.4 6.5 7.7 7.7 6.
## [127] 6.2 6.1 6.4 7.2 7.4 7.9 6.4 6.3 6.1 7.7 6.3 6.
## [145] 6.7 6.7 6.3 6.5 6.2 5.9
```

More laziness - partial matching

Tibbles do not use partial matching when the \$ operator is used.

```
head( iris$Sp )
```

```
## [1] setosa setosa setosa setosa setosa setosa  
## Levels: setosa versicolor virginica
```

```
head( iris$Species )
```

```
## [1] setosa setosa setosa setosa setosa setosa  
## Levels: setosa versicolor virginica
```

```
head(tbl_iris$Sp)
```

```
## Warning: Unknown or uninitialised column: 'Sp'.  
## NULL
```

```
head(tbl_iris$Species)
```

```
## [1] setosa setosa setosa setosa setosa setosa  
## Levels: setosa versicolor virginica
```

More laziness - stringsAsFactors

Tibbles also have always had `stringsAsFactors = FALSE` as default behavior.

```
(t = tibble(  
  x = 1:3,  
  y = c("A", "B", "C"),  
  z = factor(c("X", "Y", "Z"))  
))
```

```
## # A tibble: 3 × 3  
##       x     y     z  
##   <int> <chr> <fct>  
## 1     1     A     X  
## 2     2     B     Y  
## 3     3     C     Z
```

```
str(t)
```

```
## tibble [3 × 3] (S3: tbl_df/tbl/data.frame)  
## $ x: int [1:3] 1 2 3  
## $ y: chr [1:3] "A" "B" "C"  
## $ z: Factor w/ 3 levels "X", "Y", "Z": 1 2 3
```

```
(d = data.frame(  
  x = 1:3,  
  y = c("A", "B", "C"),  
  z = factor(c("X", "Y", "Z")),  
  stringsAsFactors = TRUE  
))
```

```
##   x     y     z  
## 1 1     A     X  
## 2 2     B     Y  
## 3 3     C     Z
```

```
str(d)
```

```
## 'data.frame': 3 obs. of 3 variables:  
## $ x: int 1 2 3  
## $ y: Factor w/ 3 levels "A", "B", "C": 1 2 3  
## $ z: Factor w/ 3 levels "X", "Y", "Z": 1 2 3
```

Tibbles and length coercion

```
data.frame(x = 1:4, y = 1)
```

```
##   x y
## 1 1 1
## 2 2 1
## 3 3 1
## 4 4 1
```

```
data.frame(x = 1:4, y = 1:2)
```

```
##   x y
## 1 1 1
## 2 2 2
## 3 3 1
## 4 4 2
```

```
data.frame(x = 1:4, y = 1:3)
```

```
## Error in data.frame(x = 1:4, y = 1:3): argument
```

```
tibble(x = 1:4, y = 1)
```

```
## # A tibble: 4 × 2
##       x     y
##   <int> <dbl>
## 1     1     1
## 2     2     1
## 3     3     1
## 4     4     1
```

```
tibble(x = 1:4, y = 1:2)
```

```
## Error: Tibble columns must have compatible sizes.
## * Size 4: Existing data.
## * Size 2: Column `y`.
## i Only values of size one are recycled.
```

```
tibble(x = 1:4, y = 1:3)
```

```
## Error: Tibble columns must have compatible sizes.
## * Size 4: Existing data.
```

Tibbles and S3

```
t = tibble(  
  x = 1:3,  
  y = c("A", "B", "C")  
)  
  
class(t)
```

```
d = data.frame(  
  x = 1:3,  
  y = c("A", "B", "C")  
)  
  
class(d)
```

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

```
methods(class="tbl_df")
```

```
## [1] [  
## [6] $<-  
## [11] Ops  
## [16] tbl_sum  
## see '?methods' for accessing help and source code
```

```
methods(class="tbl")
```

```
## [1] [[<-      [<-      $<-      coerce      format      glimpse  
## [7] initialize  Ops      print      show       slotsFromS3  tbl_sum  
## see '?methods' for accessing help and source code
```



magrittr

What is a pipe

In software engineering, a pipeline consists of a chain of processing elements (processes, threads, coroutines, functions, etc.), arranged so that the output of each element is the input of the next;

- Wikipedia - Pipeline (software)

Magrittr's pipe is a new infix operator that allows us to link two functions together in a way that is readable from left to right.

The two code examples below are equivalent,

```
f(g(x=1, y=2), n=2)
```

```
g(x=1, y=2) %>% f(n=2)
```

Readability

Consider the following sequence of actions that describe the process of getting to campus in the morning:

I need to find my key, then unlock my car, then start my car, then drive to school, then park.

Expressed as a set of nested functions in R pseudocode this would look like:

```
park(drive(start_car(find("keys")), to="campus"))
```

Writing it out using pipes give it a more natural (and easier to read) structure:

```
find("keys") %>%
  start_car() %>%
  drive(to="campus") %>%
  park()
```

Approaches

All of the following are fine, it comes down to personal preference:

Nested:

```
h( g( f(x), y=1 ), z=1 )
```

Piped:

```
f(x) %>%  
  g(y=1) %>%  
  h(z=1)
```

Intermediate:

```
res = f(x)  
res = g(res, y=1)  
res = h(res, z=1)
```

What about other arguments?

Sometimes we want to send our results to an function argument other than first one or we want to use the previous result for multiple arguments. In these cases we can refer to the previous result using ..

```
data.frame(a = 1:3, b = 3:1) %>% lm(a~b, data=.)
```

```
##  
## Call:  
## lm(formula = a ~ b, data = .)  
##  
## Coefficients:  
## (Intercept)          b  
##             4            -1
```

```
data.frame(a = 1:3, b = 3:1) %>% .[[1]]
```

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

```
data.frame(a = 1:3, b = 3:1) %>% .[[length(.)]]
```

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

The base R pipe

As of R v4.1.0 a pipe operator has been added to the base language in R, it is implemented as |>.

```
1:10 |> cumsum()  
## [1] 1 3 6 10 15 21 28 36 45 55  
  
1:10 |> cumsum() |> mean()  
## [1] 22
```

The current version of RStudio on the departmental servers is v4.0.5 but you can install a newer version on your personal machine if you want to try it out.

For this reason and a couple of other caveats listed below we will be relying on the magrittr pipe for this course.

Base R pipe considerations:

- Depending an R version ≥ 4.1 is a harder dependency than depending on the magrittr



A Grammar of Data Manipulation

dplyr is based on the concepts of functions as verbs that manipulate data frames.

Core single data frame functions / verbs:

- filter() / slice(): pick rows based on criteria
- select() / rename(): select columns by name
- pull(): grab a column as a vector
- arrange(): reorder rows
- mutate() / transmute(): create or modify columns
- distinct(): filter for unique rows
- summarise() / count(): reduce variables to values
- group_by() / ungroup(): modify other verbs to act on subsets
- relocate(): change column order

dplyr rules

1. First argument is always a data frame
2. Subsequent arguments say what to do with that data frame
3. Always return a data frame
4. Don't modify in place
5. Lazy evaluation magic

Example Data

We will demonstrate dplyr's functionality using the nycflights13 data.

```
library(dplyr)
library(nycflights13)

flights

## # A tibble: 336,776 × 19
##   year month   day dep_time sched_dep_time dep_delay arr_time sched_arr_time
##   <int> <int> <int>    <int>          <int>     <dbl>    <int>          <int>
## 1 2013     1     1      517            515        2       830            819
## 2 2013     1     1      533            529        4       850            830
## 3 2013     1     1      542            540        2       923            850
## 4 2013     1     1      544            545       -1      1004           1022
## 5 2013     1     1      554            600       -6      812            837
## 6 2013     1     1      554            558       -4      740            728
## 7 2013     1     1      555            600       -5      913            854
## 8 2013     1     1      557            600       -3      709            723
## 9 2013     1     1      557            600       -3      838            846
## 10 2013    1     1      558            600       -2      753            745
## # ... with 336,766 more rows, and 11 more variables: arr_delay <dbl>,
## #   carrier <chr>, flight <int>, tailnum <chr>, origin <chr>, dest <chr>,
## #   air_time <dbl>, distance <dbl>, hour <dbl>, minute <dbl>, time_hour <dttm>
```

filter() - March flights

```
flights %>% filter(month == 3)

## # A tibble: 28,834 × 19
##   year month   day dep_time sched_dep_time dep_delay arr_time sched_arr_time
##   <int> <int> <int>     <int>        <int>     <dbl>     <int>        <int>
## 1 2013     3     1       4            2159      125      318         56
## 2 2013     3     1      50            2358      52       526        438
## 3 2013     3     1     117            2245     152       223       2354
## 4 2013     3     1     454            500      -6       633        648
## 5 2013     3     1     505            515      -10      746        810
## 6 2013     3     1     521            530      -9       813        827
## 7 2013     3     1     537            540      -3       856        850
## 8 2013     3     1     541            545      -4      1014       1023
## 9 2013     3     1     549            600      -11      639        703
## 10 2013    3     1     550            600      -10      747        801
## # ... with 28,824 more rows, and 11 more variables: arr_delay <dbl>,
## #   carrier <chr>, flight <int>, tailnum <chr>, origin <chr>, dest <chr>,
## #   air_time <dbl>, distance <dbl>, hour <dbl>, minute <dbl>, time_hour <dttm>
```

filter() - Flights in the first 7 days of March

```
flights %>% filter(month == 3, day <= 7)
```

```
## # A tibble: 6,530 × 19
##   year month   day dep_time sched_dep_time dep_delay arr_time sched_arr_time
##   <int> <int> <int>    <int>          <int>     <dbl>    <int>          <int>
## 1 2013     3     1       4            2159      125      318          56
## 2 2013     3     1      50            2358      52       526         438
## 3 2013     3     1     117            2245     152       223        2354
## 4 2013     3     1     454            500      -6       633         648
## 5 2013     3     1     505            515     -10       746         810
## 6 2013     3     1     521            530      -9       813         827
## 7 2013     3     1     537            540      -3       856         850
## 8 2013     3     1     541            545      -4      1014        1023
## 9 2013     3     1     549            600     -11       639         703
## 10 2013    3     1     550            600     -10       747         801
## # ... with 6,520 more rows, and 11 more variables: arr_delay <dbl>,
## #   carrier <chr>, flight <int>, tailnum <chr>, origin <chr>, dest <chr>,
## #   air_time <dbl>, distance <dbl>, hour <dbl>, minute <dbl>, time_hour <dttm>
```

filter() - Flights to LAX or JFK in March

```
flights %>% filter(dest == "LAX" | dest == "JFK", month==3)
```

```
## # A tibble: 1,178 × 19
##   year month   day dep_time sched_dep_time dep_delay arr_time sched_arr_time
##   <int> <int> <int>    <int>          <int>     <dbl>    <int>        <int>
## 1 2013     3     1      607            610       -3      832        925
## 2 2013     3     1      629            632       -3      844        952
## 3 2013     3     1      657            700       -3      953       1034
## 4 2013     3     1      714            715       -1      939       1037
## 5 2013     3     1      716            710        6      958       1035
## 6 2013     3     1      727            730       -3     1007       1100
## 7 2013     3     1      836            840       -4     1111       1157
## 8 2013     3     1      857            900       -3     1202       1221
## 9 2013     3     1      903            900        3     1157       1220
## 10 2013    3     1      904            831       33     1150       1151
## # ... with 1,168 more rows, and 11 more variables: arr_delay <dbl>,
## #   carrier <chr>, flight <int>, tailnum <chr>, origin <chr>, dest <chr>,
## #   air_time <dbl>, distance <dbl>, hour <dbl>, minute <dbl>, time_hour <dttm>
```

slice() - First 10 flights

```
flights %>% slice(1:10)
```

```
## # A tibble: 10 × 19
##   year month   day dep_time sched_dep_time dep_delay arr_time sched_arr_time
##   <int> <int> <int>    <int>        <int>     <dbl>    <int>        <int>
## 1 2013     1     1      517          515        2       830        819
## 2 2013     1     1      533          529        4       850        830
## 3 2013     1     1      542          540        2       923        850
## 4 2013     1     1      544          545       -1      1004       1022
## 5 2013     1     1      554          600       -6       812        837
## 6 2013     1     1      554          558       -4       740        728
## 7 2013     1     1      555          600       -5       913        854
## 8 2013     1     1      557          600       -3       709        723
## 9 2013     1     1      557          600       -3       838        846
## 10 2013    1     1      558          600       -2       753        745
## # ... with 11 more variables: arr_delay <dbl>, carrier <chr>, flight <int>,
## #   tailnum <chr>, origin <chr>, dest <chr>, air_time <dbl>, distance <dbl>,
## #   hour <dbl>, minute <dbl>, time_hour <dttm>
```

slice() - Last 5 flights

```
flights %>% slice((n()-4):n())
```

```
## # A tibble: 5 × 19
##   year month   day dep_time sched_dep_time dep_delay arr_time sched_arr_time
##   <int> <int> <int>     <int>          <int>      <dbl>    <int>          <int>
## 1  2013     9     30       NA        1455        NA        NA        1634
## 2  2013     9     30       NA        2200        NA        NA        2312
## 3  2013     9     30       NA        1210        NA        NA        1330
## 4  2013     9     30       NA        1159        NA        NA        1344
## 5  2013     9     30       NA         840        NA        NA        1020
## # ... with 11 more variables: arr_delay <dbl>, carrier <chr>, flight <int>,
## #   tailnum <chr>, origin <chr>, dest <chr>, air_time <dbl>, distance <dbl>,
## #   hour <dbl>, minute <dbl>, time_hour <dttm>
```

```
flights %>% slice_tail(n = 5)
```

```
## # A tibble: 5 × 19
##   year month   day dep_time sched_dep_time dep_delay arr_time sched_arr_time
##   <int> <int> <int>     <int>          <int>      <dbl>    <int>          <int>
## 1 2013     9     30       NA        1455        NA        NA        1634
## 2 2013     9     30       NA        2200        NA        NA        2312
## 3 2013     9     30       NA        1210        NA        NA        1330
## 4 2013     9     30       NA        1159        NA        NA        1344
## 5 2013     9     30       NA         840        NA        NA        1020
## # ... with 11 more variables: arr_delay <dbl>, carrier <chr>, flight <int>,
## #   tailnum <chr>, origin <chr>, dest <chr>, air_time <dbl>, distance <dbl>,
## #   hour <dbl>, minute <dbl>, time_hour <dttm>
```

select() - Individual Columns

```
flights %>% select(year, month, day)
```

```
## # A tibble: 336,776 × 3
##       year   month   day
##   <int> <int> <int>
## 1 2013     1     1
## 2 2013     1     1
## 3 2013     1     1
## 4 2013     1     1
## 5 2013     1     1
## 6 2013     1     1
## 7 2013     1     1
## 8 2013     1     1
## 9 2013     1     1
## 10 2013    1     1
## # ... with 336,766 more rows
```

select() - Exclude Columns

```
flights %>% select(-year, -month, -day)
```

```
## # A tibble: 336,776 × 16
##   dep_time sched_dep_time dep_delay arr_time sched_arr_time arr_delay carrier
##   <int>       <int>     <dbl>     <int>       <int>     <dbl> <chr>
## 1      517           515        2     830         819      11  UA
## 2      533           529        4     850         830      20  UA
## 3      542           540        2     923         850      33  AA
## 4      544           545       -1    1004        1022     -18  B6
## 5      554           600       -6     812         837     -25  DL
## 6      554           558       -4     740         728      12  UA
## 7      555           600       -5     913         854      19  B6
## 8      557           600       -3     709         723     -14  EV
## 9      557           600       -3     838         846      -8  B6
## 10     558           600       -2     753         745      8  AA
## # ... with 336,766 more rows, and 9 more variables: flight <int>, tailnum <chr>,
## #   origin <chr>, dest <chr>, air_time <dbl>, distance <dbl>, hour <dbl>,
## #   minute <dbl>, time_hour <dttm>
```

select() - Ranges

```
flights %>% select(year:day)
```

```
## # A tibble: 336,776 × 3
##       year   month   day
##   <int> <int> <int>
## 1 2013     1     1
## 2 2013     1     1
## 3 2013     1     1
## 4 2013     1     1
## 5 2013     1     1
## 6 2013     1     1
## 7 2013     1     1
## 8 2013     1     1
## 9 2013     1     1
## 10 2013    1     1
## # ... with 336,766 more rows
```

select() - Exclusion Ranges

```
flights %>% select(-(year:day))

## # A tibble: 336,776 × 16
##       dep_time sched_dep_time dep_delay arr_time sched_arr_time arr_delay carrier
##       <int>        <int>     <dbl>      <int>        <int>     <dbl> <chr>
## 1        517          515       2        830        819      11  UA
## 2        533          529       4        850        830      20  UA
## 3        542          540       2        923        850      33  AA
## 4        544          545      -1       1004       1022     -18  B6
## 5        554          600      -6        812        837     -25  DL
## 6        554          558      -4        740        728      12  UA
## 7        555          600      -5        913        854      19  B6
## 8        557          600      -3        709        723     -14  EV
## 9        557          600      -3        838        846      -8  B6
## 10       558          600      -2        753        745       8  AA
## # ... with 336,766 more rows, and 9 more variables: flight <int>, tailnum <chr>,
## #   origin <chr>, dest <chr>, air_time <dbl>, distance <dbl>, hour <dbl>,
## #   minute <dbl>, time_hour <dttm>
```

select() - Matching

```
flights %>% select(contains("dep"),
                     contains("arr"))

## # A tibble: 336,776 × 7
##   dep_time sched_dep_time dep_delay arr_time sched_arr_time arr_delay carrier
##   <int>        <int>     <dbl>    <int>        <int>     <dbl> <chr>
## 1      517          515      2       830        819      11  UA
## 2      533          529      4       850        830      20  UA
## 3      542          540      2       923        850      33  AA
## 4      544          545     -1      1004       1022     -18  B6
## 5      554          600     -6      812        837     -25  DL
## 6      554          558     -4      740        728      12  UA
## 7      555          600     -5      913        854      19  B6
## 8      557          600     -3      709        723     -14  EV
## 9      557          600     -3      838        846      -8  B6
## 10     558          600     -2      753        745      8   AA
## # ... with 336,766 more rows
```

```
flights %>% select(starts_with("dep"),
                      starts_with("arr"))
```

```
## # A tibble: 336,776 × 4
##   dep_time dep_delay arr_time arr_delay
##       <int>     <dbl>     <int>     <dbl>
## 1      517        2     830       11
## 2      533        4     850       20
## 3      542        2     923       33
## 4      544       -1    1004      -18
## 5      554       -6     812      -25
## 6      554       -4     740       12
## 7      555       -5     913       19
## 8      557       -3     709      -14
## 9      557       -3     838       -8
## 10     558       -2     753        8
## # ... with 336,766 more rows
```

Other helpers provide by tidyselect:

starts_with, ends_with, everything, matches, num_range, one_of, everything, last_col.

select() + where() - Get numeric columns

```
flights %>% select(where(is.numeric))
```

```
## # A tibble: 336,776 × 14
##   year month   day dep_time sched_dep_time dep_delay arr_time sched_arr_time
##   <int> <int> <int>    <int>          <int>     <dbl>    <int>        <int>
## 1 2013     1     1      517            515        2     830        819
## 2 2013     1     1      533            529        4     850        830
## 3 2013     1     1      542            540        2     923        850
## 4 2013     1     1      544            545       -1     1004       1022
## 5 2013     1     1      554            600       -6     812        837
## 6 2013     1     1      554            558       -4     740        728
## 7 2013     1     1      555            600       -5     913        854
## 8 2013     1     1      557            600       -3     709        723
## 9 2013     1     1      557            600       -3     838        846
## 10 2013    1     1      558            600       -2     753        745
## # ... with 336,766 more rows, and 6 more variables: arr_delay <dbl>,
## #   flight <int>, air_time <dbl>, distance <dbl>, hour <dbl>, minute <dbl>
```

```
flights %>% select(where(function(x) !is.numeric(x)))
```

```
## # A tibble: 336,776 × 5
##   carrier tailnum origin dest time_hour
##   <chr>    <chr>   <chr> <chr> <dttm>
## 1 UA       N14228  EWR    IAH    2013-01-01 05:00:00
```

relocate - to the front

```
flights %>% relocate(carrier, origin, dest)
```

```
## # A tibble: 336,776 × 19
##   carrier origin dest   year month   day dep_time sched_dep_time dep_delay
##   <chr>    <chr>  <chr> <int> <int> <int>     <dbl>           <dbl>
## 1 UA       EWR    IAH    2013     1     1      517            515        2
## 2 UA       LGA    IAH    2013     1     1      533            529        4
## 3 AA       JFK    MIA    2013     1     1      542            540        2
## 4 B6       JFK    BQN    2013     1     1      544            545       -1
## 5 DL       LGA    ATL    2013     1     1      554            600       -6
## 6 UA       EWR    ORD    2013     1     1      554            558       -4
## 7 B6       EWR    FLL    2013     1     1      555            600       -5
## 8 EV       LGA    IAD    2013     1     1      557            600       -3
## 9 B6       JFK    MCO    2013     1     1      557            600       -3
## 10 AA      LGA    ORD   2013     1     1      558            600       -2
## # ... with 336,766 more rows, and 10 more variables: arr_time <int>,
## #   sched_arr_time <int>, arr_delay <dbl>, flight <int>, tailnum <chr>,
## #   air_time <dbl>, distance <dbl>, hour <dbl>, minute <dbl>, time_hour <dttm>
```

relocate - to the end

```
flights %>%  
  relocate(year, month, day, .after = last_col())  
  
## # A tibble: 336,776 × 19  
##   dep_time sched_dep_time dep_delay arr_time sched_arr_time arr_delay carrier  
##   <int>       <int>     <dbl>    <int>       <int>     <dbl> <chr>  
## 1      517          515      2        830        819      11  UA  
## 2      533          529      4        850        830      20  UA  
## 3      542          540      2        923        850      33  AA  
## 4      544          545     -1       1004       1022     -18  B6  
## 5      554          600     -6       812        837     -25  DL  
## 6      554          558     -4       740        728      12  UA  
## 7      555          600     -5       913        854      19  B6  
## 8      557          600     -3       709        723     -14  EV  
## 9      557          600     -3       838        846      -8  B6  
## 10     558          600     -2       753        745      8   AA  
## # ... with 336,766 more rows, and 12 more variables: flight <int>, tailnum <chr>,  
## #   origin <chr>, dest <chr>, air_time <dbl>, distance <dbl>, hour <dbl>,  
## #   minute <dbl>, time_hour <dttm>, year <int>, month <int>, day <int>
```

rename() - Change column names

```
flights %>% rename(tail_number = tailnum)
```

```
## # A tibble: 336,776 × 19
##   year month   day dep_time sched_dep_time dep_delay arr_time sched_arr_time
##   <int> <int> <int>    <int>        <int>     <dbl>    <int>        <int>
## 1 2013     1     1      517          515        2     830        819
## 2 2013     1     1      533          529        4     850        830
## 3 2013     1     1      542          540        2     923        850
## 4 2013     1     1      544          545       -1     1004       1022
## 5 2013     1     1      554          600       -6     812        837
## 6 2013     1     1      554          558       -4     740        728
## 7 2013     1     1      555          600       -5     913        854
## 8 2013     1     1      557          600       -3     709        723
## 9 2013     1     1      557          600       -3     838        846
## 10 2013    1     1      558          600       -2     753        745
## # ... with 336,766 more rows, and 11 more variables: arr_delay <dbl>,
## #   carrier <chr>, flight <int>, tail_number <chr>, origin <chr>, dest <chr>,
## #   air_time <dbl>, distance <dbl>, hour <dbl>, minute <dbl>, time_hour <dttm>
```

select() vs. rename()

```
flights %>% select(tail_number = tailnum)
```

```
## # A tibble: 336,776 × 1
##   tail_number
##   <chr>
## 1 N14228
## 2 N24211
## 3 N619AA
## 4 N804JB
## 5 N668DN
## 6 N39463
## 7 N516JB
## 8 N829AS
## 9 N593JB
## 10 N3ALAA
## # ... with 336,766 more rows
```

```
flights %>% rename(tail_number = tailnum)
```

```
## # A tibble: 336,776 × 19
##   year month   day dep_time sched_dep_time dep_delay arr_time sched_arr_time
##   <int> <int> <int>    <int>          <int>     <dbl>    <int>          <int>
## 1 2013     1     1      517            515       2.00     830            819
## 2 2013     1     1      533            529       4.00     850            830
```

pull()

```
names(flights)
```

```
## [1] "year"          "month"         "day"           "dep_time"  
## [5] "sched_dep_time" "dep_delay"      "arr_time"       "sched_arr_time"  
## [9] "arr_delay"      "carrier"        "flight"        "tailnum"  
## [13] "origin"         "dest"          "air_time"      "distance"  
## [17] "hour"           "minute"        "time_hour"
```

```
flights %>% pull("year") %>% head()
```

```
## [1] 2013 2013 2013 2013 2013 2013
```

```
flights %>% pull(1) %>% head()
```

```
## [1] 2013 2013 2013 2013 2013 2013
```

```
flights %>% pull(-1) %>% head()
```

```
## [1] "2013-01-01 05:00:00 EST" "2013-01-01 05:00:00 EST"  
## [3] "2013-01-01 05:00:00 EST" "2013-01-01 05:00:00 EST"  
## [5] "2013-01-01 06:00:00 EST" "2013-01-01 05:00:00 EST"
```

```
flights %>% .[["year"]] %>% head()
```

arrange() - Sort data

```
flights %>% filter(month==3,day==2) %>% arrange(origin, dest)
```

```
## # A tibble: 765 × 19
##   year month   day dep_time sched_dep_time dep_delay arr_time sched_arr_time
##   <int> <int> <int>     <int>          <int>     <dbl>    <int>        <int>
## 1 2013     3     2      1336           1329       7    1426        1432
## 2 2013     3     2       628           629      -1     837        849
## 3 2013     3     2       637           640      -3     903        915
## 4 2013     3     2       743           745      -2     945       1010
## 5 2013     3     2       857           900      -3    1117       1126
## 6 2013     3     2      1027          1030      -3    1234       1247
## 7 2013     3     2      1134          1145     -11    1332       1359
## 8 2013     3     2      1412          1415      -3    1636       1630
## 9 2013     3     2      1633          1636      -3    1848       1908
## 10 2013    3     2      1655          1700     -5    1857       1924
## # ... with 755 more rows, and 11 more variables: arr_delay <dbl>, carrier <chr>,
## #   flight <int>, tailnum <chr>, origin <chr>, dest <chr>, air_time <dbl>,
## #   distance <dbl>, hour <dbl>, minute <dbl>, time_hour <dttm>
```

arrange() & desc() - Descending order

```
flights %>%  
  filter(month==3, day==2) %>%  
  arrange(desc(origin), dest) %>%  
  select(origin, dest, tailnum)  
  
## # A tibble: 765 × 3  
##   origin dest  tailnum  
##   <chr>  <chr> <chr>  
## 1 LGA    ATL    N928AT  
## 2 LGA    ATL    N623DL  
## 3 LGA    ATL    N680DA  
## 4 LGA    ATL    N996AT  
## 5 LGA    ATL    N510MQ  
## 6 LGA    ATL    N663DN  
## 7 LGA    ATL    N942DL  
## 8 LGA    ATL    N511MQ  
## 9 LGA    ATL    N910DE  
## 10 LGA   ATL    N902DE  
## # ... with 755 more rows
```

mutate() - Modify columns

```
flights %>%  
  select(year:day) %>%  
  mutate(date = paste(year, month, day, sep="/"))
```

```
## # A tibble: 336,776 × 4  
##   year month   day date  
##   <int> <int> <int> <chr>  
## 1 2013     1     1 2013/1/1  
## 2 2013     1     1 2013/1/1  
## 3 2013     1     1 2013/1/1  
## 4 2013     1     1 2013/1/1  
## 5 2013     1     1 2013/1/1  
## 6 2013     1     1 2013/1/1  
## 7 2013     1     1 2013/1/1  
## 8 2013     1     1 2013/1/1  
## 9 2013     1     1 2013/1/1  
## 10 2013    1     1 2013/1/1  
## # ... with 336,766 more rows
```

distinct() - Find unique rows

```
flights %>%  
  select(origin, dest) %>%  
  distinct() %>%  
  arrange(origin,dest)  
  
## # A tibble: 224 × 2  
##   origin dest  
##   <chr>  <chr>  
## 1 EWR    ALB  
## 2 EWR    ANC  
## 3 EWR    ATL  
## 4 EWR    AUS  
## 5 EWR    AVL  
## 6 EWR    BDL  
## 7 EWR    BNA  
## 8 EWR    BOS  
## 9 EWR    BQN  
## 10 EWR   BTV  
## # ... with 214 more rows
```

summarise()

```
flights %>%  
  summarize(n(), min(dep_delay), max(dep_delay))
```

```
## # A tibble: 1 × 3  
##   `n()` `min(dep_delay)` `max(dep_delay)`  
##   <int>      <dbl>          <dbl>  
## 1 336776        NA            NA
```

```
flights %>%  
  summarize(  
    n = n(),  
    min_dep_delay = min(dep_delay, na.rm = TRUE),  
    max_dep_delay = max(dep_delay, na.rm = TRUE)  
)
```

```
## # A tibble: 1 × 3  
##   n min_dep_delay max_dep_delay  
##   <int>      <dbl>          <dbl>  
## 1 336776        -43            1301
```

group_by()

```
flights %>% group_by(origin)

## # A tibble: 336,776 × 19
## # Groups:   origin [3]
##   year month   day dep_time sched_dep_time dep_delay arr_time sched_arr_time
##   <int> <int> <int>    <int>          <int>    <dbl>    <int>          <int>
## 1 2013     1     1      517            515        2     830          819
## 2 2013     1     1      533            529        4     850          830
## 3 2013     1     1      542            540        2     923          850
## 4 2013     1     1      544            545       -1    1004         1022
## 5 2013     1     1      554            600       -6     812          837
## 6 2013     1     1      554            558       -4     740          728
## 7 2013     1     1      555            600       -5     913          854
## 8 2013     1     1      557            600       -3     709          723
## 9 2013     1     1      557            600       -3     838          846
## 10 2013    1     1      558            600       -2     753          745
## # ... with 336,766 more rows, and 11 more variables: arr_delay <dbl>,
## #   carrier <chr>, flight <int>, tailnum <chr>, origin <chr>, dest <chr>,
## #   air_time <dbl>, distance <dbl>, hour <dbl>, minute <dbl>, time_hour <dttm>
```

summarise() with group_by()

```
flights %>%  
  group_by(origin) %>%  
  summarize(  
    n = n(),  
    min_dep_delay = min(dep_delay, na.rm = TRUE),  
    max_dep_delay = max(dep_delay, na.rm = TRUE)  
)
```

```
## # A tibble: 3 × 4  
##   origin      n  min_dep_delay  max_dep_delay  
##   <chr>     <int>        <dbl>        <dbl>  
## 1 EWR      120835        -25        1126  
## 2 JFK      111279        -43        1301  
## 3 LGA      104662        -33         911
```

Groups after summarise

```
flights %>%  
  group_by(origin) %>%  
  summarize(  
    n = n(),  
    min_dep_delay = min(dep_delay, na.rm = TRUE),  
    max_dep_delay = max(dep_delay, na.rm = TRUE),  
    .groups = "drop_last"  
  )
```

```
## # A tibble: 3 × 4  
##   origin      n min_dep_delay max_dep_delay  
##   <chr>     <int>       <dbl>        <dbl>  
## 1 EWR      120835        -25         1126  
## 2 JFK      111279        -43         1301  
## 3 LGA      104662        -33          911
```

```
flights %>%  
  group_by(origin) %>%  
  summarize(  
    n = n(),  
    min_dep_delay = min(dep_delay, na.rm = TRUE),  
    max_dep_delay = max(dep_delay, na.rm = TRUE),  
    .groups = "keep"  
  )
```

```
## # A tibble: 3 × 4  
## # Groups:   origin [3]  
##   origin      n min_dep_delay max_dep_delay  
##   <chr>     <int>       <dbl>        <dbl>  
## 1 EWR      120835        -25         1126  
## 2 JFK      111279        -43         1301  
## 3 LGA      104662        -33          911
```

```
flights %>%  
  group_by(origin, carrier) %>%  
  summarise(  
    n = n(),  
    min_dep_delay = min(dep_delay, na.rm = TRUE),  
    max_dep_delay = max(dep_delay, na.rm = TRUE)  
) %>%  
  filter(n > 10000)
```

`summarise()` has grouped output by 'origin'. You can override using the `groups` argument.

```
## # A tibble: 10 × 5  
## # Groups:   origin [3]  
##   origin carrier     n min_dep_delay max_dep_delay  
##   <chr>   <chr> <int>      <dbl>        <dbl>  
## 1 EWR     EV       43939      -25         548  
## 2 EWR     UA       46087      -18         424  
## 3 JFK     9E       14651      -24         747  
## 4 JFK     AA       13783      -15        1014  
## 5 JFK     B6       42076      -43         453  
## 6 JFK     DL       20701      -18         960  
## 7 LGA     AA       15459      -24         803  
## 8 LGA     DL       23067      -33         911  
## 9 LGA     MQ       16928      -26         366  
## 10 LGA    US       13136      -18         500
```

count()

```
flights %>%  
  group_by(origin, carrier) %>%  
  summarize(n = n(), .groups = "drop")
```

```
## # A tibble: 35 × 3  
##   origin carrier     n  
##   <chr>  <chr>   <int>  
## 1 EWR    9E        1268  
## 2 EWR    AA        3487  
## 3 EWR    AS         714  
## 4 EWR    B6        6557  
## 5 EWR    DL        4342  
## 6 EWR    EV       43939  
## 7 EWR    MQ        2276  
## 8 EWR    OO         6  
## 9 EWR    UA       46087  
## 10 EWR   US        4405  
## # ... with 25 more rows
```

```
flights %>%  
  count(origin, carrier)
```

```
## # A tibble: 35 × 3  
##   origin carrier     n  
##   <chr>  <chr>   <int>  
## 1 EWR    9E        1268  
## 2 EWR    AA        3487  
## 3 EWR    AS         714  
## 4 EWR    B6        6557  
## 5 EWR    DL        4342  
## 6 EWR    EV       43939  
## 7 EWR    MQ        2276  
## 8 EWR    OO         6  
## 9 EWR    UA       46087  
## 10 EWR   US        4405  
## # ... with 25 more rows
```

mutate() with group_by()

```
flights %>% group_by(origin) %>%
  mutate(
    n = n(),
  ) %>%
  select(origin, n)

## # A tibble: 336,776 × 2
## # Groups:   origin [3]
##       origin     n
##       <chr>   <int>
## 1 EWR      120835
## 2 LGA      104662
## 3 JFK      111279
## 4 JFK      111279
## 5 LGA      104662
## 6 EWR      120835
## 7 EWR      120835
## 8 LGA      104662
## 9 JFK      111279
## 10 LGA     104662
## # ... with 336,766 more rows
```

Demos

1. How many flights to Los Angeles (LAX) did each of the legacy carriers (AA, UA, DL or US) have in May from JFK, and what was their average duration?
2. What was the shortest flight out of each airport in terms of distance? In terms of duration?

Exercise 1

1. Which plane (check the tail number) flew out of each New York airport the most?
2. Which date should you fly on if you want to have the lowest possible average departure delay? What about arrival delay?