

QCB 508 – Week 2

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Data Wrangling

Definition

Data wrangling is loosely defined as the process of manually converting or mapping data from one “raw” form into another format that allows for more convenient consumption of the data with the help of semi-automated tools.

It typically follows a set of general steps which begin with extracting the data in a raw form from the data source, “wrangling” the raw data using algorithms (e.g. sorting) or parsing the data into predefined data structures, and finally depositing the resulting content into a data sink for storage and future use.

From https://en.wikipedia.org/wiki/Data_wrangling

Workflow

These steps are typically taken in a data science project.

1. **Import**
2. **Tidy**
3. **Transform** ↔ Visualize ↔ Model (*iterate*)
4. Communicate

The bold terms are part of data wrangling.

Challenges

- Importing files
- Organizing data sets
- Transforming data
- Combining data sets
- Dealing with various data types (e.g., dates)
- Identifying errors

Tidy Data

Motivation

“Happy families are all alike; every unhappy family is unhappy in its own way.”
– Leo Tolstoy

“Tidy datasets are all alike, but every messy dataset is messy in its own way.” –
Hadley Wickham

From *R for Data Science*.

Definition

Tidy datasets are easy to manipulate, model and visualize, and have a specific structure: each variable is a column, each observation is a row, and each type of observational unit is a table.

From Wickham (2014), “Tidy Data”, *Journal of Statistical Software*

Definition (cont’d)

A dataset is a collection of values, usually either numbers (if quantitative) or strings (if qualitative). Values are organized in two ways. Every value belongs to a variable and an observation. A variable contains all values that measure the same underlying attribute (like height, temperature, duration) across units. An observation contains all values measured on the same unit (like a person, or a day, or a race) across attributes.

From: Wickham H (2014), “Tidy Data”, *Journal of Statistical Software*

Example: Titanic Data

According to the `Titanic` data from the `datasets` package: 367 males survived, 1364 males perished, 344 females survived, and 126 females perished.

How should we organize these data?

Intuitive Format

	Survived	Perished
Male	367	1364
Female	344	126

Tidy Format

fate	sex	number
perished	male	1364
perished	female	126
survived	male	367
survived	female	344

Rules of Thumb

1. Something is a value if it represents different forms of a common object and it changes throughout the data set.
2. Something is a value if the data can be arranged so that it appears across rows within a column and this makes sense.

For example, `fate` and `sex` do not satisfy these criteria in the `Titanic` data, but `perished/survived` and `female/male` do.

Tidyverse

Idea

When the data are in tidy format, one can design functions around this format to consistently and intuitively perform data wrangling and analysis operations. The packages containing these are called the “tidyverse.”

Note: The idea of tidy data was first proposed by Hadley Wickham and he created several of the core packages, so this used to be called (semi-seriously)

the “hadleyverse.”

Packages

The tidyverse is a set of packages that work in harmony because they share common data representations and API design. The **tidyverse** package is designed to make it easy to install and load core packages from the tidyverse in a single command.

<https://blog.rstudio.org/2016/09/15/tidyverse-1-0-0/>

Primary Packages

- **dplyr**: data manipulation
- **ggplot2**: data visualization
- **purrr**: functional programming
- **readr**: data import
- **tibble**: modernization of data frames
- **tidyr**: data tidying

Loading tidyverse

```
> library(tidyverse)
Loading tidyverse: ggplot2
Loading tidyverse: tibble
Loading tidyverse: tidyr
Loading tidyverse: readr
Loading tidyverse: purrr
Loading tidyverse: dplyr
Conflicts with tidy packages -----
filter(): dplyr, stats
lag():    dplyr, stats
```

Tidying Data

tidyr Package

This package provides a variety of functions that allow one to tidy data.

Importantly, it solves two common ways that data come as untidy.

1. **gather()**: Gathers a variable distributed across two or more columns into a single column.

2. `spread()`: Spreads a column containing two or more variables into one column per variable.

Untidy Titanic Data

This does not satisfy the definition of tidy data because a variable's observations are distributed as column names.

```
> df <- tibble(sex=c("male", "female"),
+             survived=c(367, 344),
+             perished=c(1364, 126))
> df
# A tibble: 2 × 3
  sex survived perished
<chr>   <dbl>   <dbl>
1 male     367     1364
2 female   344     126
```

`gather()`

We apply the `gather()` function to make a column containing the `survived` and `perished` observations.

```
> df <- gather(df, survived, perished,
+             key="fate", value="number")
> df
# A tibble: 4 × 3
  sex    fate number
<chr>  <chr>  <dbl>
1 male  survived    367
2 female survived    344
3 male  perished   1364
4 female perished   126
```

`spread()`

This example is here to show that `spread()` does the opposite operation as `gather()`. It isn't used appropriately here because we revert the data back to untidy format.

```
> spread(df, key=fate, value=number)
# A tibble: 2 × 3
  sex perished survived
* <chr>   <dbl>   <dbl>
```

1	female	126	344
2	male	1364	367

Tidy with `spread()`

Median cost of home and median income per city are two variables included in a single column. This means we need to use `spread()`.

```
> df
# A tibble: 4 × 3
  city median_value dollars
  <chr>      <chr>    <dbl>
1 Boston      home  527300
2 Boston    income  71738
3 Raleigh     home  215700
4 Raleigh    income  65778

> spread(df, key=median_value, value=dollars)
# A tibble: 2 × 3
  city    home income
*  <chr>  <dbl>  <dbl>
1 Boston 527300  71738
2 Raleigh 215700  65778
```

Reshaping Data

Wide vs. Long Format

Tidy data are in “wide format” in that they have a column for each variable and there is one observed unit per row.

However, sometimes it’s useful to transform to “long format.” The simplest long format data have two columns. The first column contains the variable names and the second column contains the values for the variables. There are “wider” long format data that have additional columns that identify connections between observations.

Wide format data is useful for some analyses and long format for others.

reshape2 Package

The **reshape2** package has three important functions: `melt`, `dcast`, and `acast`. It allows one to move between wide and long tidy data formats.


```

> library("reshape2")
> library("datasets")
> data(airquality, package="datasets")
> names(airquality)
[1] "Ozone" "Solar.R" "Wind" "Temp" "Month" "Day"
> dim(airquality)
[1] 153 6
> airquality <- as_tibble(airquality)

```

Air Quality Data Set

```

> head(airquality)
# A tibble: 6 × 6
  Ozone Solar.R Wind Temp Month Day
  <int>   <int> <dbl> <int> <int> <int>
1    41     190  7.4    67     5    1
2    36     118  8.0    72     5    2
3    12     149 12.6    74     5    3
4    18     313 11.5    62     5    4
5    NA      NA 14.3    56     5    5
6    28      NA 14.9    66     5    6

```

```

> tail(airquality)
# A tibble: 6 × 6
  Ozone Solar.R Wind Temp Month Day
  <int>   <int> <dbl> <int> <int> <int>
1    14      20 16.6    63     9   25
2    30     193  6.9    70     9   26
3    NA     145 13.2    77     9   27
4    14     191 14.3    75     9   28
5    18     131  8.0    76     9   29
6    20     223 11.5    68     9   30

```

Melt

Melting can be thought of as melting a piece of solid metal (wide data), so it drips into long format.

```

> aql <- melt(airquality)
No id variables; using all as measure variables
> head(aql)
  variable value
1   Ozone     41
2   Ozone     36

```

```

3   Ozone   12
4   Ozone   18
5   Ozone   NA
6   Ozone   28

```

```

> tail(aql)
  variable value
913     Day    25
914     Day    26
915     Day    27
916     Day    28
917     Day    29
918     Day    30

```

Guided Melt

In the previous example, we lose the fact that a set of measurements occurred on a particular day and month, so we can do a guided melt to keep this information.

```

> aql <- melt(airquality, id.vars = c("Month", "Day"))
> head(aql)
  Month Day variable value
1     5   1   Ozone    41
2     5   2   Ozone    36
3     5   3   Ozone    12
4     5   4   Ozone    18
5     5   5   Ozone    NA
6     5   6   Ozone    28

```

```

> tail(aql)
  Month Day variable value
607    9  25     Temp    63
608    9  26     Temp    70
609    9  27     Temp    77
610    9  28     Temp    75
611    9  29     Temp    76
612    9  30     Temp    68

```

Casting

Casting allows us to go from long format to wide format data. It can be visualized as pouring molten metal (long format) into a cast to create a solid piece of metal (wide format).

Casting is more difficult because choices have to be made to determine how the

wide format will be organized. It often takes some thought and experimentation for new users.

Let's do an example with `dcast`, which is casting for data frames.

`dcast()`

```
> aqw <- dcast(aql, Month + Day ~ variable)
> head(aqw)
  Month Day Ozone Solar.R Wind Temp
1     5   1    41     190   7.4   67
2     5   2    36     118   8.0   72
3     5   3    12     149  12.6   74
4     5   4    18     313  11.5   62
5     5   5     NA      NA  14.3   56
6     5   6    28      NA  14.9   66

> tail(aqw)
  Month Day Ozone Solar.R Wind Temp
148    9  25    14      20  16.6   63
149    9  26    30     193   6.9   70
150    9  27     NA     145  13.2   77
151    9  28    14     191  14.3   75
152    9  29    18     131   8.0   76
153    9  30    20     223  11.5   68
```

Transforming Data

`dplyr` Package

`dplyr` is a package with the following description:

A fast, consistent tool for working with data frame like objects, both in memory and out of memory.

This package offers a “grammar” for manipulating data frames.

Everything that `dplyr` does can also be done using basic R commands – however, it tends to be much faster and easier to use `dplyr`.

Grammar of `dplyr`

Verbs:

- **filter**: extract a subset of rows from a data frame based on logical conditions
- **arrange**: reorder rows of a data frame
- **rename**: rename variables in a data frame
- **select**: return a subset of the columns of a data frame, using a flexible notation

Partially based on *R Programming for Data Science*

Grammar of `dplyr`

Verbs (continued):

- **mutate**: add new variables/columns or transform existing variables
- **distinct**: returns only the unique values in a table
- **summarize**: generate summary statistics of different variables in the data frame, possibly within strata
- **group_by**: breaks down a dataset into specified groups of rows

Partially based on *R Programming for Data Science*

Example: Baby Names

```
> library("dplyr", verbose=FALSE)
> library("babynames")
> ls()
character(0)
> babynames <- as_tibble(babynames::babynames)
> ls()
[1] "babynames"
```

`babynames` Object

```
> class(babynames)
[1] "tbl_df"      "tbl"        "data.frame"
> dim(babynames)
[1] 1825433      5

> babynames
# A tibble: 1,825,433 × 5
  year  sex  name    n    prop
<dbl> <chr> <chr> <int> <dbl>
1  1880    F  Mary   7065 0.07238359
2  1880    F  Anna   2604 0.02667896
```

```

3  1880    F      Emma  2003 0.02052149
4  1880    F Elizabeth  1939 0.01986579
5  1880    F    Minnie  1746 0.01788843
6  1880    F Margaret  1578 0.01616720
7  1880    F      Ida  1472 0.01508119
8  1880    F    Alice  1414 0.01448696
9  1880    F   Bertha  1320 0.01352390
10 1880    F    Sarah  1288 0.01319605
# ... with 1,825,423 more rows

```

Peek at the Data

```

> set.seed(201)
> sample_n(babynames, 10)
# A tibble: 10 × 5
   year  sex  name      n      prop
  <dbl> <chr> <chr> <int>   <dbl>
1  1991    M Esaias     5 2.359700e-06
2  1933    F  Maida    33 3.155410e-05
3  1967    M  Alvis    33 1.853916e-05
4  1905    M Gaylord   11 7.679151e-05
5  1993    F Kyleigh  157 7.965969e-05
6  1927    M  Della     8 6.886519e-06
7  1908    F Luberta   12 3.384753e-05
8  1968    F  Andrea  7086 4.145300e-03
9  1921    F Ardelle   50 3.907288e-05
10 1955    M Dainel     7 3.351657e-06
> # try also sample_frac(babynames, 6e-6)

```

%>% Operator

Originally from R package `magrittr`. Provides a mechanism for chaining commands with a forward-pipe operator, `%>%`.

```

> x <- 1:10
>
> x %>% log(base=10) %>% sum
[1] 6.559763
>
> sum(log(x,base=10))
[1] 6.559763

> babynames %>% sample_n(5)
# A tibble: 5 × 5

```

	year	sex	name	n	prop
	<dbl>	<chr>	<chr>	<int>	<dbl>
1	1979	M	Sunil	42	2.344364e-05
2	1996	F	Kelina	5	2.608857e-06
3	1991	F	Gimena	7	3.443326e-06
4	1979	M	Neilson	9	5.023636e-06
5	1984	F	Romelia	5	2.774045e-06

filter()

```
> filter(babynames, year==1880, sex=="F")
# A tibble: 942 × 5
```

	year	sex	name	n	prop
	<dbl>	<chr>	<chr>	<int>	<dbl>
1	1880	F	Mary	7065	0.07238359
2	1880	F	Anna	2604	0.02667896
3	1880	F	Emma	2003	0.02052149
4	1880	F	Elizabeth	1939	0.01986579
5	1880	F	Minnie	1746	0.01788843
6	1880	F	Margaret	1578	0.01616720
7	1880	F	Ida	1472	0.01508119
8	1880	F	Alice	1414	0.01448696
9	1880	F	Bertha	1320	0.01352390
10	1880	F	Sarah	1288	0.01319605

```
# ... with 932 more rows
> # same as filter(babynames, year==1880 & sex=="F")
```

```
> filter(babynames, year==1880, sex=="F", n > 5000)
# A tibble: 1 × 5
```

	year	sex	name	n	prop
	<dbl>	<chr>	<chr>	<int>	<dbl>
1	1880	F	Mary	7065	0.07238359

arrange()

```
> arrange(babynames, name, year, sex)
# A tibble: 1,825,433 × 5
```

	year	sex	name	n	prop
	<dbl>	<chr>	<chr>	<int>	<dbl>
1	2007	M	Aaban	5	2.260251e-06
2	2009	M	Aaban	6	2.834029e-06
3	2010	M	Aaban	9	4.390297e-06
4	2011	M	Aaban	11	5.429927e-06

```

5  2012      M Aaban      11 5.440091e-06
6  2013      M Aaban      14 6.961721e-06
7  2014      M Aaban      16 7.882569e-06
8  2011      F Aabha       7 3.622491e-06
9  2012      F Aabha       5 2.587144e-06
10 2014      F Aabha       9 4.642684e-06
# ... with 1,825,423 more rows

```

arrange()

```

> arrange(babynames, desc(name), desc(year), sex)
# A tibble: 1,825,433 × 5
   year sex    name    n      prop
  <dbl> <chr>  <chr> <int>  <dbl>
1  2010    M   Zzyzx     5 2.439054e-06
2  2014    M   Zyyon     6 2.955964e-06
3  2010    F  Zyyanna     6 3.067323e-06
4  2009    M   Zyvion     5 2.361691e-06
5  2010    M Zytavious     6 2.926865e-06
6  2009    M Zytavious     7 3.306368e-06
7  2007    M Zytavious     6 2.712301e-06
8  2006    M Zytavious     7 3.196664e-06
9  2005    M Zytavious     5 2.352830e-06
10 2004    M Zytavious     6 2.841628e-06
# ... with 1,825,423 more rows

```

rename()

```

> rename(babynames, number=n)
# A tibble: 1,825,433 × 5
   year sex    name number    prop
  <dbl> <chr>  <chr>  <int>  <dbl>
1  1880    F     Mary   7065 0.07238359
2  1880    F     Anna   2604 0.02667896
3  1880    F     Emma   2003 0.02052149
4  1880    F Elizabeth 1939 0.01986579
5  1880    F   Minnie  1746 0.01788843
6  1880    F Margaret 1578 0.01616720
7  1880    F      Ida  1472 0.01508119
8  1880    F     Alice 1414 0.01448696
9  1880    F   Bertha 1320 0.01352390
10 1880    F     Sarah 1288 0.01319605

```

```
# ... with 1,825,423 more rows
```

select()

```
> select(babynames, sex, name, n)
# A tibble: 1,825,433 × 3
  sex      name      n
  <chr>   <chr> <int>
1     F    Mary  7065
2     F   Anna  2604
3     F   Emma  2003
4     F Elizabeth 1939
5     F  Minnie  1746
6     F Margaret 1578
7     F     Ida  1472
8     F   Alice  1414
9     F  Bertha  1320
10    F   Sarah  1288
# ... with 1,825,423 more rows
> # same as select(babynames, sex:n)
```

Renaming with select()

```
> select(babynames, sex, name, number=n)
# A tibble: 1,825,433 × 3
  sex      name number
  <chr>   <chr> <int>
1     F    Mary  7065
2     F   Anna  2604
3     F   Emma  2003
4     F Elizabeth 1939
5     F  Minnie  1746
6     F Margaret 1578
7     F     Ida  1472
8     F   Alice  1414
9     F  Bertha  1320
10    F   Sarah  1288
# ... with 1,825,423 more rows
```


`mutate()`

```
> mutate(babynames, total_by_year=round(n/prop))
# A tibble: 1,825,433 × 6
  year sex   name     n      prop total_by_year
  <dbl> <chr>   <chr> <int>   <dbl>      <dbl>
1  1880 F     Mary   7065 0.07238359  97605
2  1880 F     Anna   2604 0.02667896  97605
3  1880 F     Emma   2003 0.02052149  97605
4  1880 F Elizabeth 1939 0.01986579  97605
5  1880 F     Minnie 1746 0.01788843  97605
6  1880 F   Margaret 1578 0.01616720  97605
7  1880 F       Ida 1472 0.01508119  97605
8  1880 F      Alice 1414 0.01448696  97605
9  1880 F    Bertha 1320 0.01352390  97605
10 1880 F      Sarah 1288 0.01319605  97605
# ... with 1,825,423 more rows
> # see also transmute
```

No. Individuals by Year and Sex

Let's put a few things together now adding the function `distinct()`...

```
> babynames %>% mutate(total_by_year=round(n/prop)) %>%
+   select(sex, year, total_by_year) %>% distinct()
# A tibble: 270 × 3
  sex   year total_by_year
  <chr> <dbl>      <dbl>
1     F  1880      97605
2     M  1880     118400
3     F  1881      98856
4     M  1881     108284
5     F  1882     115698
6     M  1882     122033
7     F  1883     120064
8     M  1883     112480
9     F  1884     137588
10    M  1884     122741
# ... with 260 more rows
```

`summarize()`

```
> summarize(babynames, mean_n = mean(n), median_n = median(n),
+           number_sex = n_distinct(sex),
```

```
+ distinct_names = n_distinct(name))
# A tibble: 1 × 4
  mean_n median_n number_sex distinct_names
  <dbl>   <int>     <int>         <int>
1 184.6879      12         2         93889
```

group_by()

```
> babynames %>% group_by(year, sex)
Source: local data frame [1,825,433 x 5]
Groups: year, sex [270]

  year    sex    name     n    prop
  <dbl> <chr>   <chr> <int> <dbl>
1  1880     F    Mary   7065 0.07238359
2  1880     F    Anna   2604 0.02667896
3  1880     F    Emma   2003 0.02052149
4  1880     F Elizabeth 1939 0.01986579
5  1880     F   Minnie 1746 0.01788843
6  1880     F Margaret 1578 0.01616720
7  1880     F     Ida 1472 0.01508119
8  1880     F    Alice 1414 0.01448696
9  1880     F   Bertha 1320 0.01352390
10 1880     F    Sarah 1288 0.01319605
# ... with 1,825,423 more rows
```

No. Individuals by Year and Sex

```
> babynames %>% group_by(year, sex) %>%
+ summarize(total_by_year=sum(n))
Source: local data frame [270 x 3]
Groups: year [?]

  year    sex total_by_year
  <dbl> <chr>         <int>
1  1880     F      90993
2  1880     M     110491
3  1881     F      91954
4  1881     M     100745
5  1882     F     107850
6  1882     M     113688
7  1883     F     112321
```

```

8  1883    M    104629
9  1884    F    129022
10 1884    M    114445
# ... with 260 more rows

```

Compare to earlier slide. Why the difference?

How Many Distinct Names?

```

> babynames %>% group_by(sex) %>%
+   summarize(mean_n = mean(n),
+             distinct_names_sex = n_distinct(name))
# A tibble: 2 × 3
  sex    mean_n distinct_names_sex
<chr>   <dbl>         <int>
1 F    154.4542         64911
2 M    228.6588         39199

```

Most Popular Names

```

> top_names <- babynames %>% group_by(year, sex) %>%
+   summarize(top_name = name[which.max(n)])
>
> head(top_names)
Source: local data frame [6 x 3]
Groups: year [3]

  year    sex top_name
<dbl> <chr>   <chr>
1  1880    F    Mary
2  1880    M    John
3  1881    F    Mary
4  1881    M    John
5  1882    F    Mary
6  1882    M    John

```

Most Popular Names

Recent Years

```

> tail(top_names, n=10)
Source: local data frame [10 x 3]

```

Groups: year [5]

	year	sex	top_name
	<dbl>	<chr>	<chr>
1	2010	F	Isabella
2	2010	M	Jacob
3	2011	F	Sophia
4	2011	M	Jacob
5	2012	F	Sophia
6	2012	M	Jacob
7	2013	F	Sophia
8	2013	M	Noah
9	2014	F	Emma
10	2014	M	Noah

Most Popular Female Names

1990s

```
> top_names %>% filter(year >= 1990 & year < 2000, sex=="F")
Source: local data frame [10 x 3]
Groups: year [10]
```

	year	sex	top_name
	<dbl>	<chr>	<chr>
1	1990	F	Jessica
2	1991	F	Ashley
3	1992	F	Ashley
4	1993	F	Jessica
5	1994	F	Jessica
6	1995	F	Jessica
7	1996	F	Emily
8	1997	F	Emily
9	1998	F	Emily
10	1999	F	Emily

Most Popular Male Names

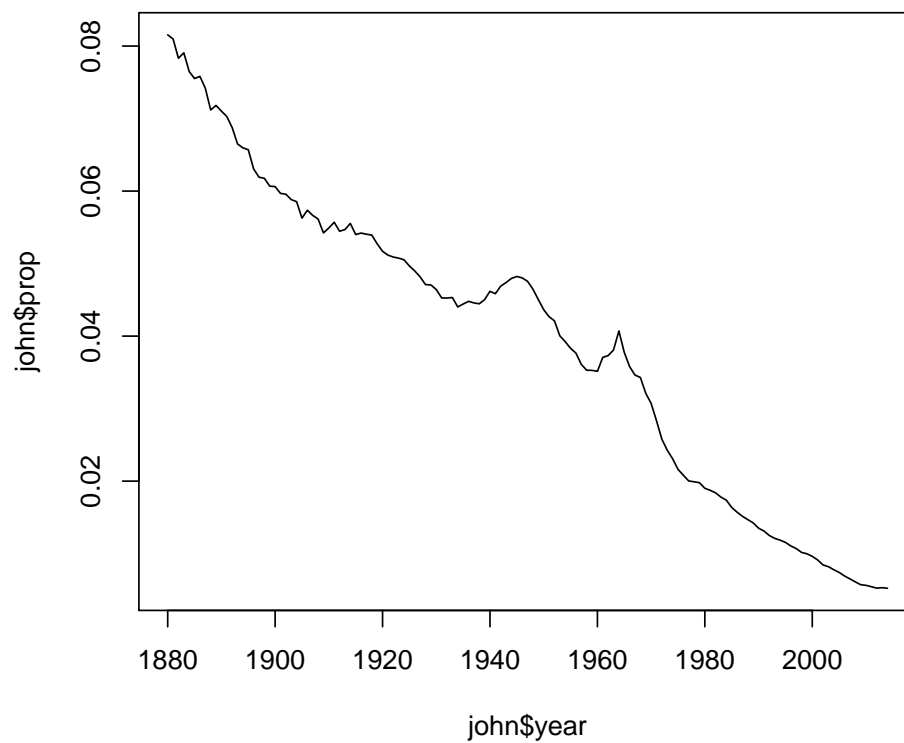
1990s

```
> top_names %>% filter(year >= 1990 & year < 2000, sex=="M")
Source: local data frame [10 x 3]
```

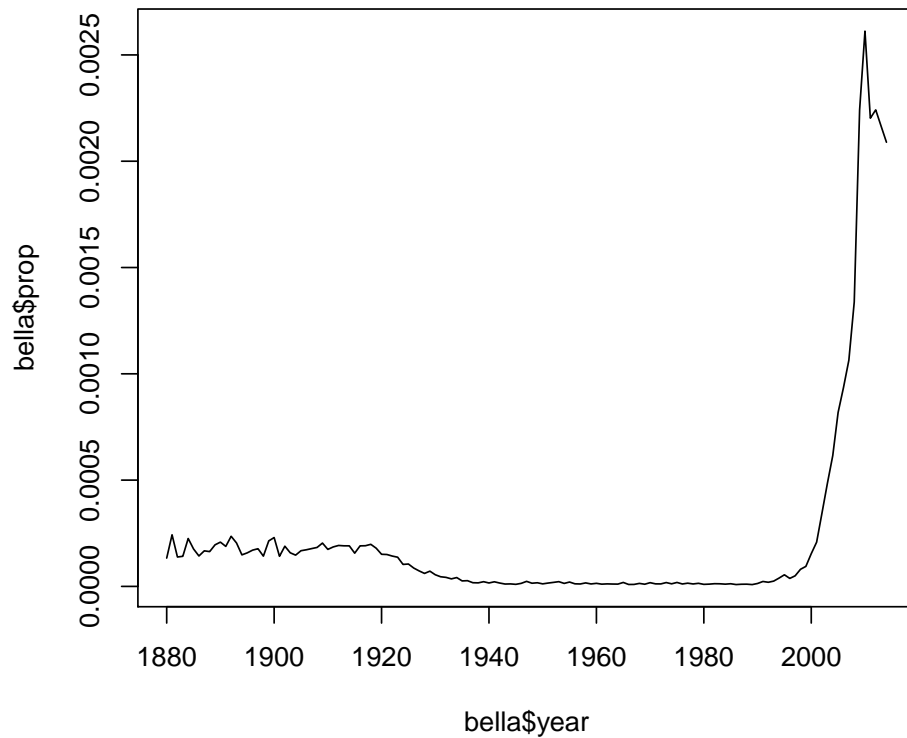
Groups: year [10]

	year	sex	top_name
	<dbl>	<chr>	<chr>
1	1990	M	Michael
2	1991	M	Michael
3	1992	M	Michael
4	1993	M	Michael
5	1994	M	Michael
6	1995	M	Michael
7	1996	M	Michael
8	1997	M	Michael
9	1998	M	Michael
10	1999	M	Jacob

```
> # Analyzing the name 'John'
> john <- babynames %>% filter(sex=="M", name=="John")
> plot(john$year, john$prop, type="l")
```



```
> # Analyzing the name 'Bella'
> bella <- babynames %>% filter(sex=="F", name=="Bella")
> plot(bella$year, bella$prop, type="l")
```



Additional Examples

You should study additional tutorials of `dplyr` that utilize other data sets:

- Read the `dplyr` introductory vignette
- Read the examples given in *R Programming for Data Science*, the “Managing Data Frames with the `dplyr` Package” chapter

Additional `dplyr` Features

- We’ve only scratched the surface – many interesting demos of `dplyr` can be found online
- `dplyr` can work with other data frame backends such as SQL databases
- There is an SQL interface for relational databases via the `DBI` package
- `dplyr` can be integrated with the `data.table` package for large fast tables
- There is a healthy rivalry between `dplyr` and `data.table`

Relational Data

Multiple Data Sets

In many data analyses you will have multiple tables of related data that must be combined in order to carry out your analysis.

The `dplyr` package includes a number of tools to facilitate this.

Toy Example

Here are two data frames that are related through a common variable called `key`.

```
> x <- tibble(key = c(1, 2, 3), x_val = c("x1", "x2", "x3"))
> y <- tibble(key = c(1, 2, 4), y_val = c("y1", "y2", "y4"))
```

```
> x
# A tibble: 3 × 2
  key x_val
<dbl> <chr>
1     1    x1
2     2    x2
3     3    x3
> y
# A tibble: 3 × 2
  key y_val
<dbl> <chr>
1     1    y1
2     2    y2
3     4    y4
```

Verbs

To work with relational data you need verbs that work with pairs of tables. There are three families of verbs designed to work with relational data.

- *Mutating joins* add new variables to one data frame from matching observations in another.
- *Filtering joins* filter observations from one data frame based on whether or not they match an observation in the other table.
- *Set operations* treat observations as if they were set elements.

From *R for Data Science*

inner_join()

An inner-join matches pairs of observations when their keys are equal.

```
> inner_join(x, y, key="key")
Joining, by = "key"
# A tibble: 2 × 3
  key x_val y_val
<dbl> <chr> <chr>
1     1    x1    y1
2     2    x2    y2
```

left_join()

A left-join keeps all observations in the first argument, x.

```
> left_join(x, y, key="key")
Joining, by = "key"
# A tibble: 3 × 3
  key x_val y_val
<dbl> <chr> <chr>
1     1    x1    y1
2     2    x2    y2
3     3    x3 <NA>
```

```
> x %>% left_join(y, key="key")
Joining, by = "key"
# A tibble: 3 × 3
  key x_val y_val
<dbl> <chr> <chr>
1     1    x1    y1
2     2    x2    y2
3     3    x3 <NA>
```

right_join()

A right-join keeps all observations in the second argument, y.

```
> right_join(x, y)
Joining, by = "key"
# A tibble: 3 × 3
  key x_val y_val
<dbl> <chr> <chr>
1     1    x1    y1
2     2    x2    y2
3     4 <NA>    y4
```


full_join()

A full-join keeps all observations in either argument, `x` or `y`.

```
> full_join(x, y, key="key")
Joining, by = "key"
# A tibble: 4 × 3
  key x_val y_val
<dbl> <chr> <chr>
1     1    x1    y1
2     2    x2    y2
3     3    x3 <NA>
4     4 <NA>    y4
```

anti_join()

An anti-join removes all observations in the first argument, `x`, that appear in the second argument, `y`.

```
> anti_join(x, y, key="key")
Joining, by = "key"
# A tibble: 1 × 2
  key x_val
<dbl> <chr>
1     3    x3
```

semi_join()

A semi-join keeps all observations in the first argument, `x`, that have a match in the second argument, `y`.

```
> semi_join(x, y, key="key")
Joining, by = "key"
# A tibble: 2 × 2
  key x_val
<dbl> <chr>
1     1    x1
2     2    x2
```

Repeated Key Values

When one of the two data frames has repeated `key` values, the observations are repeated in the other data frame.

```

> y2
# A tibble: 4 × 2
  key y_val
<dbl> <chr>
1     1    y1
2     2   y2a
3     2   y2b
4     4    y4

> x %>% left_join(y2, key="key")
Joining, by = "key"
# A tibble: 4 × 3
  key x_val y_val
<dbl> <chr> <chr>
1     1    x1    y1
2     2    x2   y2a
3     2    x2   y2b
4     3    x3  <NA>

```

Set Operations

- `intersect(x, y)`: return only observations in both `x` and `y`
- `union(x, y)`: return unique observations in `x` and `y`
- `setdiff(x, y)`: return observations in `x`, but not in `y`

From *R for Data Science*

Example `setdiff()`

```

> df1
# A tibble: 2 × 2
  x     y
<dbl> <dbl>
1     1     1
2     2     1

> df2
# A tibble: 2 × 2
  x     y
<dbl> <dbl>
1     1     1
2     1     2

> setdiff(df1, df2)
# A tibble: 1 × 2
  x     y

```

```
<dbl> <dbl>
1      2      1
```

Getting Data In and Out of R

.RData Files

R objects can be saved to binary `.RData` files and loaded with the `save` (or `save.image`) and `load` functions, respectively.

This is the easiest way to get data into R.

readr Package

There are a number of R packages that provide more sophisticated tools for getting data in and out of R, especially as data sets have become larger and larger.

One of those packages is `readr` for text files. It reads and writes data quickly, provides a useful status bar for large files, and does a good job at determining data types.

`readr` is organized similarly to the base R functions. For example, there are functions `read_table`, `read_csv`, `write_tsv`, and `write_csv`.

See also `fread` and `fwrite` from the `data.table` package.

Scraping from the Web (Ex. 1)

There are several packages that facilitate “scraping” data from the web, including `rvest` demonstrated here.

```
> library("rvest")
> schedule <- read_html("http://jdstorey.github.io/asdscourse/schedule/")
> first_table <- html_table(schedule)[[1]]
> names(first_table) <- c("week", "topics", "reading")
> first_table[2, "week"]
[1] 2
> first_table[2, "topics"] %>% strsplit(split=" ")
[[1]]
[1] "Data Wrangling"
> first_table[2, "reading"] %>% strsplit(split=" ")
[[1]]
[1] "R4DS Ch. 5, 9-16"
```

```
> grep("R4DS", first_table$reading)
[1] 1 2 3
```

Scraping from the Web (Ex. 2)

The `rvest` documentation recommends SelectorGadget, which is “a javascript bookmarklet that allows you to interactively figure out what css selector you need to extract desired components from a page.”

```
> usg_url <- "http://princetonusg.com/meet-your-usg-officers/"
> usg <- read_html(usg_url)
> officers <- html_nodes(usg, ".team-member-name") %>%
+   html_text
> head(officers, n=20)
[1] "Aleksandra Czulak" "Jeremy Burton"
[3] "Hunter Dong"      "Daniel Qian"
[5] "Sung Won Chang"   "Pooja Patel"
[7] "Miranda Rosen"    "Michael Asparrin"
[9] "Devin Kilpatrick" "Pritika Mehra"
[11] "Olivia Grah"      "Lucas Ramos"
[13] "Ellie Shannon"    "Nicholas Wu"
[15] "Wendy Zhao"       "Kishan Bhatt"
[17] "Cailin Hong"      "Myesha Jemison"
[19] "Eli Schechner"    "Ruby Guo"
```

APIs

API stands for “application programming interface” which is a set of routines, protocols, and tools for building software and applications.

A specific website may provide an API for scraping data from that website.

There are R packages that provide an interface with specific APIs, such as the `twitterR` package.

Case Study

Yeast Genomics

Smith and Kruglyak (2008) is a study that measured 2820 genotypes in 109 yeast F1 segregants from a cross between parental lines BY and RM.

They also measured gene expression on 4482 genes in each of these segregants when growing in two different Carbon sources, glucose and ethanol.

Load Data

The data was distributed as a collection of matrices in R.

```
> rm(list=ls())
> load("../data/smith_kruglyak.RData")
> ls()
[1] "exp.e"      "exp.g"      "exp.pos"    "marker"
[5] "marker.pos"
> eapply(env=.GlobalEnv, dim)
$exp.e
[1] 4482 109

$exp.g
[1] 4482 109

$marker
[1] 2820 109

$exp.pos
[1] 4482 3

$marker.pos
[1] 2820 2
```

Gene Expression Matrices

```
> exp.g %>% cbind(rownames(exp.g), .) %>% as_tibble() %>%
+   print()
# A tibble: 4,482 × 110
      <chr> X100g.20_4_c.glucose X101g.21_1_d.glucose
1 YJR107W      0.22          0.18
2 YPL270W     -0.29          -0.2
3 YDR518W      0.72           0.04
4 YDR233C      0.23           0.31
5 YHR098C      0.4            -0.04
6 YFR029W     -0.36           0.35
7 YPL198W      0.23          -0.21
8 YDR001C     -0.09           0.57
9 YLR394W     -0.23           0.13
10 YCR079W    -0.25          -0.98
# ... with 4,472 more rows, and 107 more variables:
#   X102g.21_2_d.glucose <chr>, X103g.21_3_d.glucose <chr>,
#   X104g.21_4_d.glucose <chr>, X105g.21_5_c.glucose <chr>,
```

```

# X106g.22_2_d.glucose <chr>, X107g.22_3_b.glucose <chr>,
# X109g.22_5_d.glucose <chr>, X10g.2_5_d.glucose <chr>,
# X110g.23_3_d.glucose <chr>, X111g.23_5_d.glucose <chr>,
# X112g.24_1_d.glucose <chr>, X113g.25_1_d.glucose <chr>,
# X114g.25_3_d.glucose <chr>, X115g.25_4_d.glucose <chr>,
# X116g.26_1_d.glucose <chr>, X117g.26_2_d.glucose <chr>,
# X11g.2_6_d.glucose <chr>, X12g.2_7_a.glucose <chr>,
# X13g.3_1_d.glucose <chr>, X15g.3_3_d.glucose <chr>,
# X16g.3_4_d.glucose <chr>, X17g.3_5_d.glucose <chr>,
# X18g.4_1_c.glucose <chr>, X1g.1_1_d.glucose <chr>,
# X20g.4_3_d.glucose <chr>, X21g.4_4_d.glucose <chr>,
# X22g.5_1_d.glucose <chr>, X23g.5_2_d.glucose <chr>,
# X24g.5_3_d.glucose <chr>, X25g.5_4_d.glucose <chr>,
# X26g.5_5_d.glucose <chr>, X27g.6_1_d.glucose <chr>,
# X28g.6_2_b.glucose <chr>, X29g.6_3_c.glucose <chr>,
# X30g.6_4_d.glucose <chr>, X31g.6_5_d.glucose <chr>,
# X32g.6_6_d.glucose <chr>, X33g.6_7_d.glucose <chr>,
# X34g.7_1_d.glucose <chr>, X35g.7_2_c.glucose <chr>,
# X36g.7_3_d.glucose <chr>, X37g.7_4_c.glucose <chr>,
# X38g.7_5_d.glucose <chr>, X39g.7_6_c.glucose <chr>,
# X3g.1_3_d.glucose <chr>, X40g.7_7_c.glucose <chr>,
# X41g.7_8_d.glucose <chr>, X42g.8_1_a.glucose <chr>,
# X43g.8_2_d.glucose <chr>, X44g.8_3_a.glucose <chr>,
# X45g.8_4_c.glucose <chr>, X46g.8_5_b.glucose <chr>,
# X47g.8_6_c.glucose <chr>, X48g.8_7_b.glucose <chr>,
# X49g.9_1_d.glucose <chr>, X4g.1_4_d.glucose <chr>,
# X50g.9_2_d.glucose <chr>, X51g.9_3_d.glucose <chr>,
# X52g.9_4_d.glucose <chr>, X53g.9_5_d.glucose <chr>,
# X54g.9_6_d.glucose <chr>, X55g.9_7_d.glucose <chr>,
# X56g.10_1_c.glucose <chr>, X57g.10_2_d.glucose <chr>,
# X58g.10_3_c.glucose <chr>, X59g.10_4_d.glucose <chr>,
# X5g.1_5_c.glucose <chr>, X60g.11_1_a.glucose <chr>,
# X61g.11_2_d.glucose <chr>, X62g.11_3_b.glucose <chr>,
# X63g.12_1_d.glucose <chr>, X64g.12_2_b.glucose <chr>,
# X65g.13_1_a.glucose <chr>, X66g.13_2_c.glucose <chr>,
# X67g.13_3_b.glucose <chr>, X68g.13_4_a.glucose <chr>,
# X69g.13_5_c.glucose <chr>, X70g.14_1_b.glucose <chr>,
# X71g.14_2_c.glucose <chr>, X73g.14_4_a.glucose <chr>,
# X74g.14_5_b.glucose <chr>, X75g.14_6_d.glucose <chr>,
# X76g.14_7_c.glucose <chr>, X77g.15_2_d.glucose <chr>,
# X78g.15_3_b.glucose <chr>, X79g.15_4_d.glucose <chr>,
# X7g.2_2_d.glucose <chr>, X80g.15_5_b.glucose <chr>,
# X82g.16_1_d.glucose <chr>, X83g.17_1_a.glucose <chr>,
# X84g.17_2_d.glucose <chr>, X85g.17_4_a.glucose <chr>,
# X86g.17_5_b.glucose <chr>, X87g.18_1_d.glucose <chr>,
# X88g.18_2_d.glucose <chr>, X89g.18_3_d.glucose <chr>,

```

```
# X8g.2_3_d.glucose <chr>, X90g.18_4_c.glucose <chr>,
# X92g.19_1_c.glucose <chr>, X93g.19_2_c.glucose <chr>, ...
```

Gene Position Matrix

```
> exp.pos %>% cbind(rownames(exp.pos), .) %>% as_tibble() %>%
+ print()
# A tibble: 4,482 × 4
  Chromosome Start_coord End_coord
  <chr>      <chr>      <chr>      <chr>
1 YJR107W    10        627333    628319
2 YPL270W    16        30482     32803
3 YDR518W     4       1478600   1480153
4 YDR233C     4       930353    929466
5 YHR098C     8       301937    299148
6 YFR029W     6       210925    212961
7 YPL198W    16       173151    174701
8 YDR001C     4       452472    450217
9 YLR394W    12       907950    909398
10 YCR079W     3       252842    254170
# ... with 4,472 more rows
```

Row Names

The gene names are contained in the row names.

```
> head(rownames(exp.g))
[1] "YJR107W" "YPL270W" "YDR518W" "YDR233C" "YHR098C" "YFR029W"
> head(rownames(exp.e))
[1] "YJR107W" "YPL270W" "YDR518W" "YDR233C" "YHR098C" "YFR029W"
> head(rownames(exp.pos))
[1] "YJR107W" "YPL270W" "YDR518W" "YDR233C" "YHR098C" "YFR029W"
> all.equal(rownames(exp.g), rownames(exp.e))
[1] TRUE
> all.equal(rownames(exp.g), rownames(exp.pos))
[1] TRUE
```

Unify Column Names

The segregants are column names, and they are inconsistent across matrices.

```
> head(colnames(exp.g))
[1] "X100g.20_4_c.glucose" "X101g.21_1_d.glucose"
```

```

[3] "X102g.21_2_d.glucose" "X103g.21_3_d.glucose"
[5] "X104g.21_4_d.glucose" "X105g.21_5_c.glucose"
> head(colnames(marker))
[1] "20_4_c" "21_1_d" "21_2_d" "21_3_d" "21_4_d" "21_5_c"
>
> #fix column names with gsub
> colnames(exp.g) %<>% strsplit(split=".", fixed=TRUE) %>%
+   lapply(function(x) {x[2]})
> colnames(exp.e) %<>% strsplit(split=".", fixed=TRUE) %>%
+   lapply(function(x) {x[2]})
> head(colnames(exp.g))
[1] "20_4_c" "21_1_d" "21_2_d" "21_3_d" "21_4_d" "21_5_c"

```

Gene Positions

Let's first pull out rownames of `exp.pos` and make them a column in the data frame.

```

> gene_pos <- exp.pos %>% as_tibble() %>%
+   mutate(gene = rownames(exp.pos)) %>%
+   dplyr::select(gene, chr = Chromosome, start = Start_coord,
+                 end = End_coord)
> print(gene_pos, n=7)
# A tibble: 4,482 × 4
   gene   chr  start    end
  <chr> <int>  <int>  <int>
1 YJR107W    10  627333  628319
2 YPL270W    16   30482   32803
3 YDR518W     4 1478600 1480153
4 YDR233C     4   930353  929466
5 YHR098C     8   301937  299148
6 YFR029W     6   210925  212961
7 YPL198W    16  173151  174701
# ... with 4,475 more rows

```

Tidy Each Expression Matrix

We melt the expression matrices and bind them together into one big tidy data frame.

```

> exp_g <- melt(exp.g) %>% as_tibble() %>%
+   dplyr::select(gene = Var1, segregant = Var2,
+                 expression = value) %>%
+   mutate(condition = "glucose")

```



```

> exp_e <- melt(exp.e) %>% as_tibble() %>%
+   dplyr::select(gene = Var1, segregant = Var2,
+                 expression = value) %>%
+   mutate(condition = "ethanol")
> print(exp_e, n=4)
# A tibble: 488,538 × 4
   gene segregant expression condition
   <fctr>    <fctr>      <dbl>    <chr>
1 YJR107W   20_4_c        0.06    ethanol
2 YPL270W   20_4_c       -0.13    ethanol
3 YDR518W   20_4_c       -0.94    ethanol
4 YDR233C   20_4_c        0.04    ethanol
# ... with 4.885e+05 more rows

```

Combine Into Single Data Frame

Combine gene expression data from two conditions into a single data frame.

```

> exp_all <- bind_rows(exp_g, exp_e)
> sample_n(exp_all, size=10)
# A tibble: 10 × 4
   gene segregant expression condition
   <fctr>    <fctr>      <dbl>    <chr>
1 YBL087C   21_4_d       -0.72    ethanol
2 YDR524C   21_2_d       -0.17    glucose
3 YGR067C    9_1_d       -3.92    glucose
4 YHR207C   26_1_d       -0.43    ethanol
5 YDR329C   20_2_d       -0.06    glucose
6 YGL121C    8_7_b        1.00    ethanol
7 YJR044C    3_3_d       -0.12    ethanol
8 YIL088C    2_7_a        0.10    ethanol
9 YML127W    5_1_d       -0.08    ethanol
10 YMR304W    6_1_d        0.20    ethanol

```

Join Gene Positions

Now we want to join the gene positions with the expression data.

```

> exp_all <- exp_all %>%
+   mutate(gene = as.character(gene),
+          segregant = as.character(segregant))
> sk_tidy <- exp_all %>%
+   left_join(gene_pos, by = "gene")
> sample_n(sk_tidy, size=7)

```

```
# A tibble: 7 × 7
```

	gene	segregant	expression	condition	chr	start	end
	<chr>	<chr>	<dbl>	<chr>	<int>	<int>	<int>
1	YGL189C	1_3_d	-0.26	ethanol	7	148594	148235
2	YBR257W	13_2_c	0.02	ethanol	2	728880	729719
3	YER098W	21_1_d	0.46	ethanol	5	355462	357726
4	YCRO35C	9_1_d	0.07	glucose	3	193014	191830
5	YBR097W	17_5_b	-0.03	glucose	2	436945	441309
6	YBR235W	8_4_c	-0.18	ethanol	2	686896	690258
7	YJL094C	14_6_d	0.00	glucose	10	254437	251816

Apply dplyr Functions

Now that we have the data made tidy in the data frame `sk_tidy`, let's apply some `dplyr` operations...

Does each gene have the same number of observations?

```
> sk_tidy %>% group_by(gene) %>%
+   summarize(value = n()) %>%
+   summary()
```

gene	value
Length:4478	Min. :218.0
Class :character	1st Qu.:218.0
Mode :character	Median :218.0
	Mean :218.6
	3rd Qu.:218.0
	Max. :872.0

No, so let's see which genes have more than one set of observations.

```
> sk_tidy %>% group_by(gene) %>%
+   summarize(value = n()) %>%
+   filter(value > median(value))
```

```
# A tibble: 4 × 2
```

	gene	value
	<chr>	<int>
1	YFR024C-A	872
2	YJL012C	872
3	YKL198C	872
4	YPR089W	872

Let's remove replicated measurements for these genes.

```
> sk_tidy %<% distinct(gene, segregant, condition,
+                      .keep_all = TRUE)
>
```

```
> sk_tidy %>% group_by(gene) %>%
+   summarize(value = n()) %>%
+   summary()
      gene              value
Length:4478      Min.   :218
Class :character  1st Qu.:218
Mode  :character  Median :218
                        Mean  :218
                        3rd Qu.:218
                        Max.   :218
```

As an exercise, think about how you would use `dplyr` to replace the replicated gene expression values with a single averaged expression value for these genes.

Get the mean and standard deviation expression per chromosome.

```
> sk_tidy %>%
+   group_by(chr) %>%
+   summarize(mean = mean(expression), sd=sd(expression))
# A tibble: 16 × 3
   chr      mean      sd
<int>    <dbl>    <dbl>
1     1 -0.07618458 0.8257397
2     2 -0.04471450 0.6322533
3     3 -0.02296456 0.6815490
4     4 -0.02325893 0.5368523
5     5 -0.05793524 0.6098741
6     6 -0.07721815 0.6598159
7     7 -0.04409662 0.6174735
8     8 -0.04743984 0.6377910
9     9 -0.04298423 0.6144313
10    10 -0.02994634 0.5701558
11    11 -0.03964107 0.6130319
12    12 -0.05146305 0.6432055
13    13 -0.02646819 0.5835865
14    14 -0.02943206 0.6423964
15    15 -0.01301063 0.5544749
16    16 -0.03681626 0.6044444
```

Get the mean and standard deviation expression per chromosome in each condition.

```
> sk_tidy %>%
+   group_by(chr, condition) %>%
+   summarize(mean = mean(expression), sd=sd(expression))
Source: local data frame [32 x 4]
Groups: chr [?]
```

	chr	condition	mean	sd
	<int>	<chr>	<dbl>	<dbl>
1	1	ethanol	0.0260098709	0.4796494
2	1	glucose	-0.1783790350	1.0549134
3	2	ethanol	0.0131661446	0.4793614
4	2	glucose	-0.1025951501	0.7503419
5	3	ethanol	0.0001644526	0.5360078
6	3	glucose	-0.0460935780	0.8004235
7	4	ethanol	0.0018726571	0.4817756
8	4	glucose	-0.0483905104	0.5857082
9	5	ethanol	-0.0297045435	0.4787130
10	5	glucose	-0.0861659403	0.7163443

... with 22 more rows

Count the number of genes per chromosome.

```
> sk_tidy %>%
+   filter(condition == "glucose", segregant == "20_4_c") %>%
+   group_by(chr) %>%
+   summarize(num.genes = n())
# A tibble: 16 × 2
   chr num.genes
<int>   <int>
1     1       60
2     2      298
3     3      125
4     4      629
5     5      207
6     6       79
7     7      395
8     8      209
9     9      152
10    10      256
11    11      241
12    12      387
13    13      367
14    14      319
15    15      388
16    16      366
```

Filter for the first gene on every chromosome.

```
> sk_tidy %>%
+   filter(condition == "glucose", segregant == "20_4_c") %>%
+   group_by(chr) %>%
+   filter(start == min(start))
Source: local data frame [16 x 7]
```

Groups: chr [16]

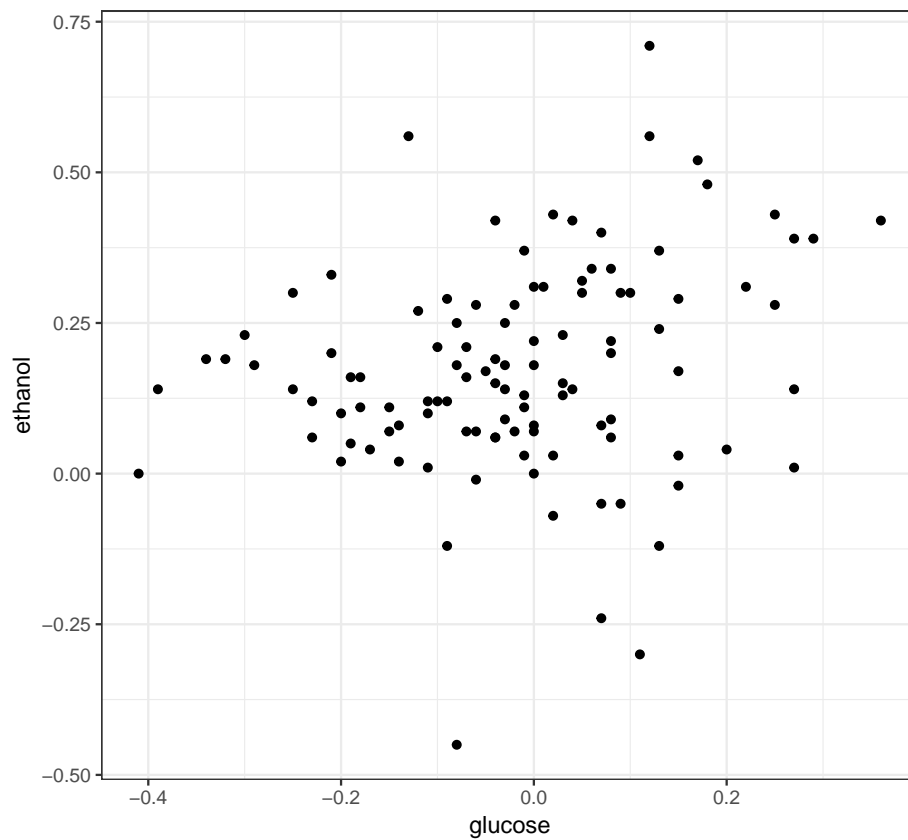
	gene	segregant	expression	condition	chr	start	end
	<chr>	<chr>	<dbl>	<chr>	<int>	<int>	<int>
1	YHL040C	20_4_c	-2.79	glucose	8	20968	19085
2	YNL334C	20_4_c	-0.90	glucose	14	12876	12208
3	YOL157C	20_4_c	-1.06	glucose	15	24293	22524
4	YKL222C	20_4_c	0.09	glucose	11	5621	3504
5	YIL168W	20_4_c	-1.14	glucose	9	29032	29415
6	YJL213W	20_4_c	0.84	glucose	10	32163	33158
7	YPL272C	20_4_c	-0.18	glucose	16	28164	26611
8	YLL063C	20_4_c	-0.66	glucose	12	16072	14648
9	YFL048C	20_4_c	-0.09	glucose	6	40180	38843
10	YML132W	20_4_c	-0.21	glucose	13	7244	8383
11	YGL261C	20_4_c	-0.14	glucose	7	6652	6290
12	YBL107C	20_4_c	0.29	glucose	2	10551	9961
13	YDL248W	20_4_c	-0.68	glucose	4	1802	2953
14	YEL073C	20_4_c	-0.02	glucose	5	7553	7230
15	YAL062W	20_4_c	-5.64	glucose	1	31568	32941
16	YCL068C	20_4_c	0.47	glucose	3	12285	11503

To plot expression in glucose versus ethanol we first need to use `dcast()`.

```
> sk_tidy %>% dcast(gene + segregant ~ condition,
+                   value.var = "expression") %>%
+   as_tibble()
# A tibble: 488,102 × 4
   gene segregant ethanol glucose
   <chr>      <chr>    <dbl>    <dbl>
1 YAL002W    1_1_d      0.37    -0.01
2 YAL002W    1_3_d      0.23     0.03
3 YAL002W    1_4_d      0.08     0.07
4 YAL002W    1_5_c     -0.12     0.13
5 YAL002W   10_1_c      0.12    -0.10
6 YAL002W   10_2_d      0.10    -0.20
7 YAL002W   10_3_c      0.07    -0.15
8 YAL002W   10_4_d      0.06    -0.04
9 YAL002W   11_1_a      0.07    -0.07
10 YAL002W   11_2_d      0.30     0.10
# ... with 488,092 more rows
```

```
> sk_tidy %>% dcast(gene + segregant ~ condition,
+                   value.var = "expression") %>%
+   filter(gene == "YAL002W") %>%
+   ggplot(aes(x = glucose, y = ethanol)) +
+   geom_point() + theme_bw() +
```

```
+ theme(legend.position = "none")
```



Extras

Source

License

Source Code

Session Information

```
> sessionInfo()  
R version 3.3.2 (2016-10-31)  
Platform: x86_64-apple-darwin13.4.0 (64-bit)
```

```

Running under: macOS Sierra 10.12.3

locale:
[1] en_US.UTF-8/en_US.UTF-8/en_US.UTF-8/C/en_US.UTF-8/en_US.UTF-8

attached base packages:
[1] stats      graphics  grDevices  utils      datasets  methods
[7] base

other attached packages:
[1] rvest_0.3.2      xml2_1.1.1      babynames_0.2.1
[4] reshape2_1.4.2  dplyr_0.5.0     purrr_0.2.2
[7] readr_1.0.0      tidyr_0.6.1     tibble_1.2
[10] ggplot2_2.2.1   tidyverse_1.1.1 knitr_1.15.1
[13] magrittr_1.5     devtools_1.12.0

loaded via a namespace (and not attached):
[1] Rcpp_0.12.9      plyr_1.8.4      forcats_0.2.0
[4] tools_3.3.2      digest_0.6.12   lubridate_1.6.0
[7] jsonlite_1.2     evaluate_0.10   memoise_1.0.0
[10] nlme_3.1-131     gtable_0.2.0    lattice_0.20-34
[13] psych_1.6.12     DBI_0.5-1       curl_2.3
[16] yaml_2.1.14      parallel_3.3.2  haven_1.0.0
[19] withr_1.0.2      stringr_1.1.0   httr_1.2.1
[22] hms_0.3          rprojroot_1.2   grid_3.3.2
[25] R6_2.2.0         XML_3.98-1.5    readxl_0.1.1
[28] foreign_0.8-67   rmarkdown_1.3   selectr_0.3-1
[31] modelr_0.1.0     backports_1.0.5 scales_0.4.1
[34] htmltools_0.3.5  assertthat_0.1  mnormt_1.5-5
[37] colorspace_1.3-2 labeling_0.3     stringi_1.1.2
[40] lazyeval_0.2.0   munsell_0.4.3   broom_0.4.1

```