

# GR5206: lecture 7

*Computational Statistics  
And Introduction to Data Science*

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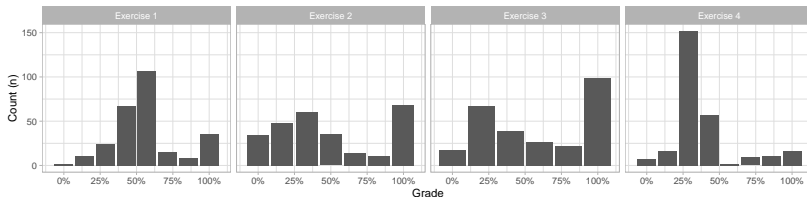
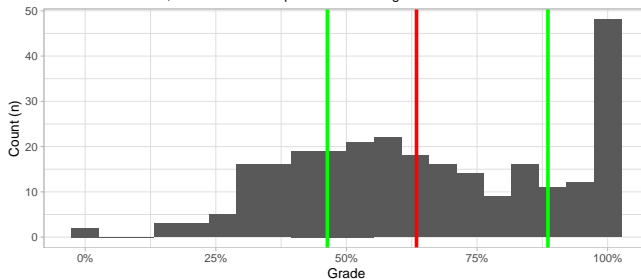
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10/25/2019

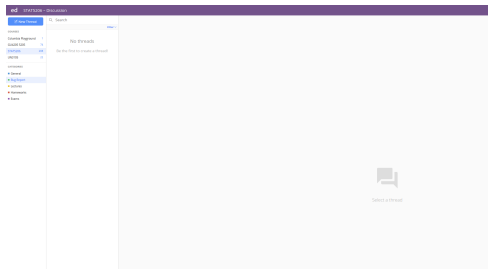
# The midterm

## Midterm Grade Distribution:

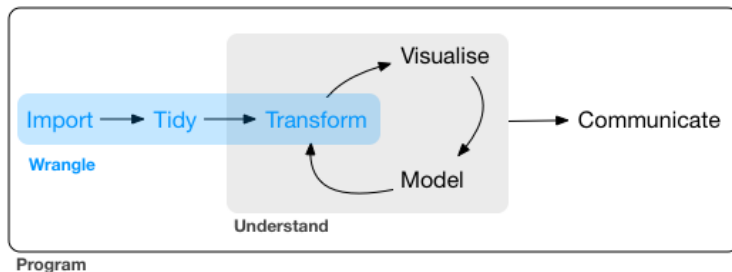
The median is in red, the 25th and 75th percentiles are in green.



- Two important updates this week solving:
  - ▶ Most RStudio crashes.
  - ▶ Memory overloads.
- A new discussion category to file bug reports:
  - ▶ Ed people will follow this closely!
  - ▶ Post there when you have an issue with:
    - Platform stability (e.g., crashes).
    - Missing features (e.g., toggle to fullscreen in SEB)



- Regarding interaction between Ed/SEB and your laptop:
  - ▶ Test in advance!
  - ▶ For instance, use SEB to complete parts of your HW...
- Regarding the room connectivity issues:
  - ▶ Either better rooms on Friday, December 8th.
    - **Most likely in the evening, save the date!**
    - **Discussing with colleagues will get you an automatic F!**
  - ▶ Or paper exam (MCQ).
- Regarding the course's grade:
  - ▶ I will increase of the weight of the final (over that of the midterm) if you improve!



Most of the material (e.g., the picture above) is borrowed from

**R for data science**

- 1 Relational data
- 2 Combining tables
- 3 Dates and times
- 4 Factors
- 5 Strings

1 Relational data

2 Combining tables

3 Dates and times

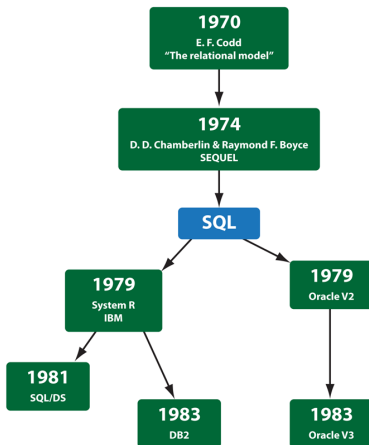
4 Factors

5 Strings

- Until now: analysis of a single table of data.
- Typically: multiple tables of data to be combined.
  - ▶ Called **relational data**:
    - Because relations, not just the individual datasets, are important.
    - Relations are always defined for a pair of tables.
    - Relations of three or more tables are built from the relations between pairs.



- Common place to find relational data.
- Oracle, MySQL, Microsoft SQL Server, PostgreSQL, IBM DB2, Microsoft Access, SQLite, and others.



- All 336,776 flights that departed from NYC in 2013 (US BTS):

flights

```
#> # A tibble: 336,776 x 19
#>   year month   day dep_time sched_dep_time dep_delay arr_time
#>   <int> <int> <int>   <int>         <int>      <dbl>    <int>
#> 1  2013     1     1     517           515         2      830
#> 2  2013     1     1     533           529         4      850
#> 3  2013     1     1     542           540         2      923
#> 4  2013     1     1     544           545        -1     1004
#> 5  2013     1     1     554           600        -6      812
#> 6  2013     1     1     554           558        -4      740
#> 7  2013     1     1     555           600        -5      913
#> 8  2013     1     1     557           600        -3      709
#> 9  2013     1     1     557           600        -3      838
#> 10 2013     1     1     558           600        -2      753
#> # ... with 336,766 more rows, and 12 more variables:
#> #   sched_arr_time <int>, arr_delay <dbl>, carrier <chr>,
#> #   flight <int>, tailnum <chr>, origin <chr>, dest <chr>,
#> #   air_time <dbl>, distance <dbl>, hour <dbl>, minute <dbl>,
#> #   time_hour <dtm>
```

## airlines

```
#> # A tibble: 16 x 2
#>   carrier name
#>   <chr>      <chr>
#> 1 9E        Endeavor Air Inc.
#> 2 AA        American Airlines Inc.
#> 3 AS        Alaska Airlines Inc.
#> 4 B6        JetBlue Airways
#> 5 DL        Delta Air Lines Inc.
#> 6 EV        ExpressJet Airlines Inc.
#> 7 F9        Frontier Airlines Inc.
#> 8 FL        AirTran Airways Corporation
#> 9 HA        Hawaiian Airlines Inc.
#> 10 MQ       Envoy Air
#> 11 OO       SkyWest Airlines Inc.
#> 12 UA       United Air Lines Inc.
#> 13 US       US Airways Inc.
#> 14 VX       Virgin America
#> 15 WN       Southwest Airlines Co.
#> 16 YV       Mesa Airlines Inc.
```

## airports

```
#> # A tibble: 1,458 x 8
```

#>	faa	name	lat	lon	alt	tz	dst	tzone
#>	<chr>	<chr>	<dbl>	<dbl>	<int>	<dbl>	<chr>	<chr>
#> 1	04G	Lansdowne Airport	41.1	-80.6	1044	-5	A	America/Ne~
#> 2	06A	Moton Field Muni~	32.5	-85.7	264	-6	A	America/Ch~
#> 3	06C	Schaumburg Regio~	42.0	-88.1	801	-6	A	America/Ch~
#> 4	06N	Randall Airport	41.4	-74.4	523	-5	A	America/Ne~
#> 5	09J	Jekyll Island Ai~	31.1	-81.4	11	-5	A	America/Ne~
#> 6	0A9	Elizabethton Mun~	36.4	-82.2	1593	-5	A	America/Ne~
#> 7	0G6	Williams County ~	41.5	-84.5	730	-5	A	America/Ne~
#> 8	0G7	Finger Lakes Reg~	42.9	-76.8	492	-5	A	America/Ne~
#> 9	0P2	Shoestring Aviat~	39.8	-76.6	1000	-5	U	America/Ne~
#> 10	0S9	Jefferson County~	48.1	-123.	108	-8	A	America/Lo~

```
#> # ... with 1,448 more rows
```

planes

```
#> # A tibble: 3,322 x 9
#>   tailnum year type manufacturer model engines seats speed engine
#>   <chr>   <int> <chr>   <chr>         <chr>   <int> <int> <int> <chr>
#> 1 N10156  2004 Fixed~ EMBRAER      EMB~      2    55    NA Turbo~
#> 2 N102UW  1998 Fixed~ AIRBUS      INDU~    A320~    2   182    NA Turbo~
#> 3 N103US  1999 Fixed~ AIRBUS      INDU~    A320~    2   182    NA Turbo~
#> 4 N104UW  1999 Fixed~ AIRBUS      INDU~    A320~    2   182    NA Turbo~
#> 5 N10575  2002 Fixed~ EMBRAER      EMB~      2    55    NA Turbo~
#> 6 N105UW  1999 Fixed~ AIRBUS      INDU~    A320~    2   182    NA Turbo~
#> 7 N107US  1999 Fixed~ AIRBUS      INDU~    A320~    2   182    NA Turbo~
#> 8 N108UW  1999 Fixed~ AIRBUS      INDU~    A320~    2   182    NA Turbo~
#> 9 N109UW  1999 Fixed~ AIRBUS      INDU~    A320~    2   182    NA Turbo~
#> 10 N110UW 1999 Fixed~ AIRBUS      INDU~    A320~    2   182    NA Turbo~
#> # ... with 3,312 more rows
```

weather

```
#> # A tibble: 26,115 x 15
```

```
#>   origin year month   day hour temp dewp humid wind_dir
```

```
#>   <chr>   <dbl> <dbl> <int> <int> <dbl> <dbl> <dbl>   <dbl>
```

```
#> 1 EWR      2013     1     1     1  39.0  26.1  59.4     270
```

```
#> 2 EWR      2013     1     1     2  39.0  27.0  61.6     250
```

```
#> 3 EWR      2013     1     1     3  39.0  28.0  64.4     240
```

```
#> 4 EWR      2013     1     1     4  39.9  28.0  62.2     250
```

```
#> 5 EWR      2013     1     1     5  39.0  28.0  64.4     260
```

```
#> 6 EWR      2013     1     1     6  37.9  28.0  67.2     240
```

```
#> 7 EWR      2013     1     1     7  39.0  28.0  64.4     240
```

```
#> 8 EWR      2013     1     1     8  39.9  28.0  62.2     250
```

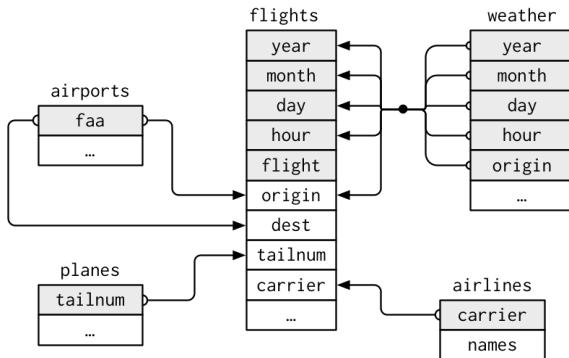
```
#> 9 EWR      2013     1     1     9  39.9  28.0  62.2     260
```

```
#> 10 EWR     2013     1     1    10  41    28.0  59.6     260
```

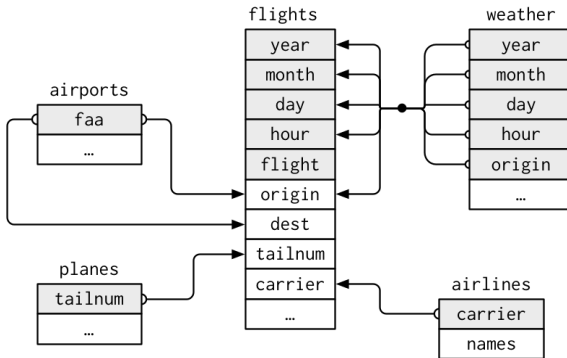
```
#> # ... with 26,105 more rows, and 6 more variables: wind_speed <dbl>,
```

```
#> #   wind_gust <dbl>, precip <dbl>, pressure <dbl>, visib <dbl>,
```

```
#> #   time_hour <dtm>
```



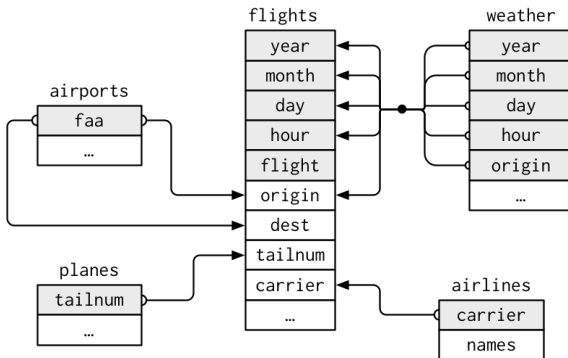
# Exercise 1



- Imagine you wanted to draw (approximately) the route each plane flies from its origin to its destination.
  - ▶ What variables would you need?
  - ▶ What tables would you need to combine?

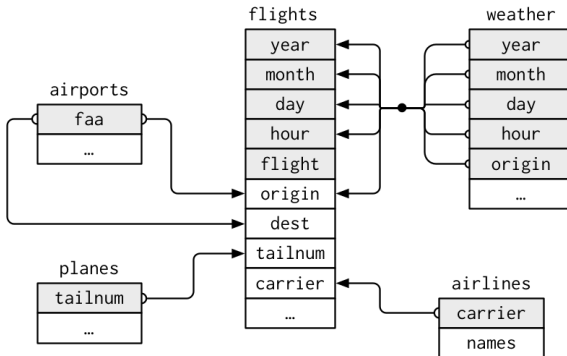


## Exercise 2



- I forgot to draw the relationship between **weather** and **airports**.
  - ▶ What is the relationship and how should it appear in the diagram?

## Exercise 3



- weather only contains information for the origin (NYC) airports.
  - ▶ If it contained weather records for all airports in the USA, what additional relation would it define with **flights**?

- Keys:
  - ▶ Variables used to connect pair of tables.
  - ▶ Uniquely identifies an observation.
  - ▶ Can be:
    - A single variable (e.g., tailnum for planes).
    - Multiple variables (e.g., year, month, day, hour, and origin for weather).
- Two types of **keys**:
  - ▶ **Primary**: uniquely identifies an observation **in its own table**.
    - E.g., planes\$tailnum.
  - ▶ **Foreign**: uniquely identifies an observation **in another table**.
    - E.g., flights\$tailnum.
- Note that:
  - ▶ A variable can be both a primary key *and* a foreign key.
  - ▶ A primary key and the corresponding foreign key in another table form a **relation**.
  - ▶ Relations are typically one-to-many (e.g., flights and planes).

# Is a given key primary?

```
planes %>%  
  count(tailnum) %>%  
  filter(n > 1)  
#> # A tibble: 0 x 2  
#> # ... with 2 variables: tailnum <chr>, n <int>
```

```
weather %>%  
  count(year, month, day, hour, origin) %>%  
  filter(n > 1)  
#> # A tibble: 3 x 6  
#>   year month   day hour origin     n  
#>   <dbl> <dbl> <int> <int> <chr>  <int>  
#> 1  2013    11     3     1 EWR      2  
#> 2  2013    11     3     1 JFK      2  
#> 3  2013    11     3     1 LGA      2
```

# No explicit primary key?

```
flights %>%
  count(year, month, day, flight) %>%
  filter(n > 1)
#> # A tibble: 29,768 x 5
#>   year month   day flight     n
#>   <int> <int> <int>   <int> <int>
#> 1  2013     1     1       1     2
#> 2  2013     1     1       3     2
#> 3  2013     1     1       4     2
#> 4  2013     1     1      11     3
#> 5  2013     1     1      15     2
#> 6  2013     1     1      21     2
#> 7  2013     1     1      27     4
#> 8  2013     1     1      31     2
#> 9  2013     1     1      32     2
#> 10 2013     1     1      35     2
#> # ... with 29,758 more rows
```

- Solution: add one with `mutate()` and `row_number()`.
- This is called a **surrogate key**.

1 Relational data

2 Combining tables

3 Dates and times

4 Factors

5 Strings

- Two families of verbs 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.

# Create a narrower dataset

```
flights2 <- flights %>%  
  select(year:day, hour, origin, dest, tailnum, carrier)
```

```
flights2
```

```
#> # A tibble: 336,776 x 8
```

```
#>   year month   day hour origin dest tailnum carrier  
#>   <int> <int> <int> <dbl> <chr> <chr> <chr> <chr>  
#> 1  2013     1     1     5 EWR  IAH  N14228  UA  
#> 2  2013     1     1     5 LGA  IAH  N24211  UA  
#> 3  2013     1     1     5 JFK  MIA  N619AA  AA  
#> 4  2013     1     1     5 JFK  BQN  N804JB  B6  
#> 5  2013     1     1     6 LGA  ATL  N668DN  DL  
#> 6  2013     1     1     5 EWR  ORD  N39463  UA  
#> 7  2013     1     1     6 EWR  FLL  N516JB  B6  
#> 8  2013     1     1     6 LGA  IAD  N829AS  EV  
#> 9  2013     1     1     6 JFK  MCO  N593JB  B6  
#> 10 2013     1     1     6 LGA  ORD  N3ALAA  AA  
#> # ... with 336,766 more rows
```



# A simple example

```
flights2 %>%
  select(-origin, -dest) %>%
  left_join(airlines, by = "carrier")
#> # A tibble: 336,776 x 7
#>   year month   day hour tailnum carrier name
#>   <int> <int> <int> <dbl> <chr>   <chr>   <chr>
#> 1  2013     1     1     5 N14228  UA      United Air Lines Inc.
#> 2  2013     1     1     5 N24211  UA      United Air Lines Inc.
#> 3  2013     1     1     5 N619AA  AA      American Airlines Inc.
#> 4  2013     1     1     5 N804JB  B6      JetBlue Airways
#> 5  2013     1     1     6 N668DN  DL      Delta Air Lines Inc.
#> 6  2013     1     1     5 N39463  UA      United Air Lines Inc.
#> 7  2013     1     1     6 N516JB  B6      JetBlue Airways
#> 8  2013     1     1     6 N829AS  EV      ExpressJet Airlines Inc.
#> 9  2013     1     1     6 N593JB  B6      JetBlue Airways
#> 10 2013     1     1     6 N3ALAA  AA      American Airlines Inc.
#> # ... with 336,766 more rows
```

# Why mutating join?

```
flights2 %>%
  select(-origin, -dest) %>%
  mutate(name = airlines$name[match(carrier, airlines$carrier)])
```

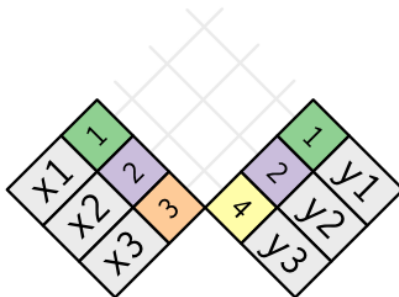
#> # A tibble: 336,776 x 7

#>	year	month	day	hour	tailnum	carrier	name
#>	<int>	<int>	<int>	<dbl>	<chr>	<chr>	<chr>
#> 1	2013	1	1	5	N14228	UA	United Air Lines Inc.
#> 2	2013	1	1	5	N24211	UA	United Air Lines Inc.
#> 3	2013	1	1	5	N619AA	AA	American Airlines Inc.
#> 4	2013	1	1	5	N804JB	B6	JetBlue Airways
#> 5	2013	1	1	6	N668DN	DL	Delta Air Lines Inc.
#> 6	2013	1	1	5	N39463	UA	United Air Lines Inc.
#> 7	2013	1	1	6	N516JB	B6	JetBlue Airways
#> 8	2013	1	1	6	N829AS	EV	ExpressJet Airlines Inc.
#> 9	2013	1	1	6	N593JB	B6	JetBlue Airways
#> 10	2013	1	1	6	N3ALAA	AA	American Airlines Inc.

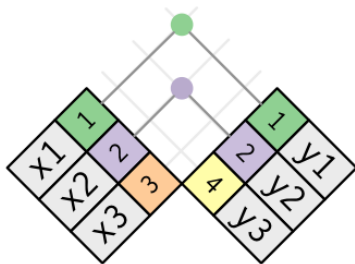
#> # ... with 336,766 more rows

# Understanding mutating joins

```
x <- tribble(~key, ~val_x,  
  1, "x1",  
  2, "x2",  
  3, "x3")  
y <- tribble(~key, ~val_y,  
  1, "y1",  
  2, "y2",  
  4, "y3")
```



# Inner join

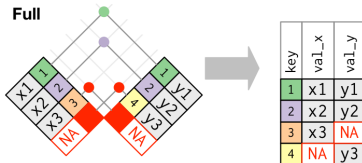
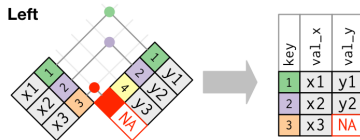


key	val_x	val_y
1	x1	y1
2	x2	y2

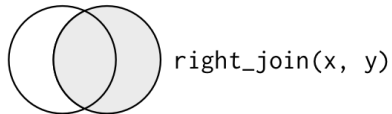
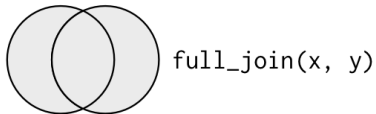
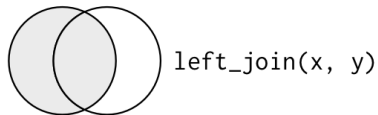
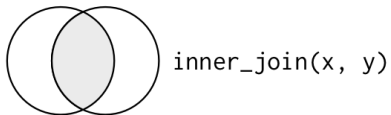
```
x %>%  
  inner_join(y, by = "key")  
#> # A tibble: 2 x 3  
#>   key val_x val_y  
#>   <dbl> <chr> <chr>  
#> 1     1   x1    y1  
#> 2     2   x2    y2
```

- **Outer joins** keep observations that appear in at least one of the tables:
  - ▶ **Left join:** keeps all observations in  $x$ .
  - ▶ **Right join:** keeps all observations in  $y$ .
  - ▶ **Full join:** keeps all observations in  $x$  and  $y$
- They work by adding to each table an additional “virtual” observation which
  - ▶ has a key that always matches (if no other key matches),
  - ▶ and a value filled with NA.

# Outer joins II



# A Venn diagram for joins



- Two possibilities:
  - ▶ One table has duplicate keys.
    - Useful to add in additional information as there is typically a one-to-many relationship.
  - ▶ Both tables have duplicate keys.
    - Usually an error because in neither table do the keys uniquely identify an observation.
    - When you join duplicated keys, you get all possible combinations (i.e., the Cartesian product).



# One table has duplicate keys

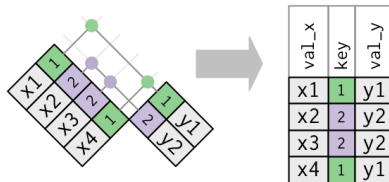
- Only x has duplicated keys:

```
x <- tribble(~key, ~val_x,  
            1, "x1",  
            2, "x2",  
            2, "x3",  
            1, "x4")
```

```
y <- tribble(~key, ~val_y,  
            1, "y1",  
            2, "y2")
```

- The join adds val\_y to the matching rows:

```
left_join(x, y, by = "key")  
#> # A tibble: 4 x 3  
#>   key val_x val_y  
#>   <dbl> <chr> <chr>  
#> 1     1    x1    y1  
#> 2     2    x2    y2  
#> 3     2    x3    y2  
#> 4     1    x4    y1
```



# Both tables have duplicate keys

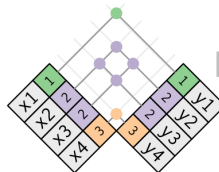
- Both x and y have duplicated keys:

```
x <- tribble(~key, ~val_x,  
            1, "x1",  
            2, "x2",  
            2, "x3",  
            3, "x4")
```

```
y <- tribble(~key, ~val_y,  
            1, "y1",  
            2, "y2",  
            2, "y3",  
            3, "y4")
```

- The joint creates all combinations:

```
left_join(x, y, by = "key")  
#> # A tibble: 6 x 3  
#>   key val_x val_y  
#>   <dbl> <chr> <chr>  
#> 1     1 x1    y1  
#> 2     2 x2    y2  
#> 3     2 x2    y3  
#> 4     2 x3    y2  
#> 5     2 x3    y3  
#> 6     3 x4    y4
```



key	val_x	val_y
1	x1	y1
2	x2	y2
2	x2	y3
2	x3	y2
2	x3	y3
3	x4	y4

# Defining the key columns

- Default uses all variables that appear in both tables.
- Called a **natural join**.

```
flights2 %>%
```

```
  left_join(weather)
```

```
#> Joining, by = c("year", "month", "day", "hour", "origin")
```

```
#> # A tibble: 336,776 x 18
```

```
#>   year month   day hour origin dest tailnum carrier temp dewp
#>   <dbl> <dbl> <int> <dbl> <chr>  <chr> <chr>   <chr>   <dbl> <dbl>
#> 1  2013     1     1     5  EWR   IAH   N14228  UA      39.0  28.0
#> 2  2013     1     1     5  LGA   IAH   N24211  UA      39.9  25.0
#> 3  2013     1     1     5  JFK   MIA   N619AA  AA      39.0  27.0
#> 4  2013     1     1     5  JFK   BQN   N804JB  B6      39.0  27.0
#> 5  2013     1     1     6  LGA   ATL   N668DN  DL      39.9  25.0
#> 6  2013     1     1     5  EWR   ORD   N39463  UA      39.0  28.0
#> 7  2013     1     1     6  EWR   FLL   N516JB  B6      37.9  28.0
#> 8  2013     1     1     6  LGA   IAD   N829AS  EV      39.9  25.0
#> 9  2013     1     1     6  JFK   MCO   N593JB  B6      37.9  27.0
#> 10 2013     1     1     6  LGA   ORD   N3ALAA  AA      39.9  25.0
#> # ... with 336,766 more rows, and 8 more variables: humid <dbl>,
#> #   wind_dir <dbl>, wind_speed <dbl>, wind_gust <dbl>, precip <dbl>,
#> #   pressure <dbl>, visib <dbl>, time_hour <dtm>
```

- Like a natural join, but uses only some of the common variables:

```
flights2 %>%  
  left_join(planes, by = "tailnum")  
#> # A tibble: 336,776 x 16  
#>   year.x month   day hour origin dest tailnum carrier year.y type  
#>   <int> <int> <int> <dbl> <chr> <chr> <chr>   <chr>   <int> <chr>  
#> 1  2013     1     1     5 EWR   IAH   N14228   UA      1999 Fixe~  
#> 2  2013     1     1     5 LGA   IAH   N24211   UA      1998 Fixe~  
#> 3  2013     1     1     5 JFK   MIA   N619AA   AA      1990 Fixe~  
#> 4  2013     1     1     5 JFK   BQN   N804JB   B6      2012 Fixe~  
#> 5  2013     1     1     6 LGA   ATL   N668DN   DL      1991 Fixe~  
#> 6  2013     1     1     5 EWR   ORD   N39463   UA      2012 Fixe~  
#> 7  2013     1     1     6 EWR   FLL   N516JB   B6      2000 Fixe~  
#> 8  2013     1     1     6 LGA   IAD   N829AS   EV      1998 Fixe~  
#> 9  2013     1     1     6 JFK   MCO   N593JB   B6      2004 Fixe~  
#> 10 2013     1     1     6 LGA   ORD   N3ALAA   AA      NA <NA>  
#> # ... with 336,766 more rows, and 6 more variables:  
#> #   manufacturer <chr>, model <chr>, engines <int>, seats <int>,  
#> #   speed <int>, engine <chr>
```

- With `by = c("a" = "b")`, `left_join` matches variable `a` in table `x` to variable `b` in table `y`:

```
flights2 %>%
  left_join(airports, c("dest" = "faa"))
#> # A tibble: 336,776 x 15
#>   year month   day hour origin dest tailnum carrier name lat
#>   <int> <int> <int> <dbl> <chr> <chr> <chr> <chr> <chr> <dbl>
#> 1  2013     1     1     5   EWR   IAH  N14228   UA   Geor~  30.0
#> 2  2013     1     1     5   LGA   IAH  N24211   UA   Geor~  30.0
#> 3  2013     1     1     5   JFK   MIA  N619AA   AA   Miam~  25.8
#> 4  2013     1     1     5   JFK   BQN  N804JB   B6   <NA>   NA
#> 5  2013     1     1     6   LGA   ATL  N668DN   DL   Hart~  33.6
#> 6  2013     1     1     5   EWR   ORD  N39463   UA   Chic~  42.0
#> 7  2013     1     1     6   EWR   FLL  N516JB   B6   Fort~  26.1
#> 8  2013     1     1     6   LGA   IAD  N829AS   EV   Wash~  38.9
#> 9  2013     1     1     6   JFK   MCO  N593JB   B6   Orla~  28.4
#> 10 2013     1     1     6   LGA   ORD  N3ALAA   AA   Chic~  42.0
#> # ... with 336,766 more rows, and 5 more variables: lon <dbl>,
#> #   alt <int>, tz <dbl>, dst <chr>, tzone <chr>
```

- `base::merge()` can perform all four types of mutating join:

dplyr	merge
<code>inner_join(x, y)</code>	<code>merge(x, y)</code>
<code>left_join(x, y)</code>	<code>merge(x, y, all.x = TRUE)</code>
<code>right_join(x, y)</code>	<code>merge(x, y, all.y = TRUE),</code>
<code>full_join(x, y)</code>	<code>merge(x, y, all.x = TRUE, all.y = TRUE)</code>

- Advantages of the specific dplyr verbs:
  - ▶ More clearly convey the intent of your code.
  - ▶ Considerably faster and don't mess with the order of the rows.
  - ▶ Conversion to SQL using `dbplyr`.

- SQL is the inspiration for dplyr's conventions:

dplyr	SQL
<code>inner_join(x, y, by = "z")</code>	<code>SELECT * FROM x INNER JOIN y USING (z)</code>
<code>left_join(x, y, by = "z")</code>	<code>SELECT * FROM x LEFT OUTER JOIN y USING (z)</code>
<code>right_join(x, y, by = "z")</code>	<code>SELECT * FROM x RIGHT OUTER JOIN y USING (z)</code>
<code>full_join(x, y, by = "z")</code>	<code>SELECT * FROM x FULL OUTER JOIN y USING (z)</code>

- Note that:
  - ▶ “INNER” and “OUTER” are optional, and often omitted.
  - ▶ Joining different variables between the tables uses a slightly different syntax in SQL.
    - E.g. `inner_join(x, y, by = c("a" = "b"))` vs `SELECT * FROM x INNER JOIN y ON x.a = y.b.`

- Similar to mutating joins, but affect the observations rather than the variables:
  - ▶ `semi_join(x, y)` **keeps** all observations in x that have a match in y.
    - Useful for matching filtered summary tables back to the original rows.
  - ▶ `anti_join(x, y)` **drops** all observations in x that have a match in y.
    - Useful for diagnosing join mismatches.



# Flights that went to top destinations

```
top_dest <- flights %>%  
  count(dest, sort = TRUE) %>%  
  head(10)  
  
flights %>%  
  filter(dest %in% top_dest$dest) %>%  
  print(n = 5)  
  
#> # A tibble: 141,145 x 19  
#>   year month   day dep_time sched_dep_time dep_delay arr_time  
#>   <int> <int> <int>   <int>         <int>       <dbl>   <int>  
#> 1  2013     1     1     542           540         2     923  
#> 2  2013     1     1     554           600        -6     812  
#> 3  2013     1     1     554           558        -4     740  
#> 4  2013     1     1     555           600        -5     913  
#> 5  2013     1     1     557           600        -3     838  
#> # ... with 1.411e+05 more rows, and 12 more variables:  
#> #   sched_arr_time <int>, arr_delay <dbl>, carrier <chr>,  
#> #   flight <int>, tailnum <chr>, origin <chr>, dest <chr>,  
#> #   air_time <dbl>, distance <dbl>, hour <dbl>, minute <dbl>,  
#> #   time_hour <dtm>
```

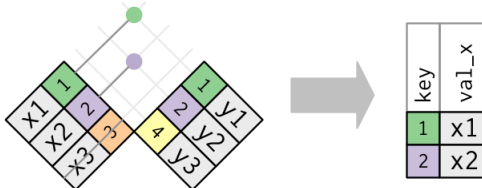
## ■ How to extend to multiple variables?

- Only keeps rows in x having a match in y:

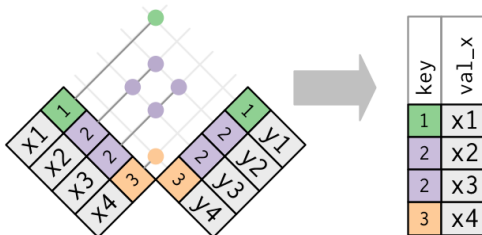
```
flights %>%
  semi_join(top_dest)
#> Joining, by = "dest"
#> # A tibble: 141,145 x 19
#>   year month   day dep_time sched_dep_time dep_delay arr_time
#>   <int> <int> <int>   <int>         <int>         <dbl>   <int>
#> 1  2013     1     1     542             540           2     923
#> 2  2013     1     1     554             600          -6     812
#> 3  2013     1     1     554             558          -4     740
#> 4  2013     1     1     555             600          -5     913
#> 5  2013     1     1     557             600          -3     838
#> 6  2013     1     1     558             600          -2     753
#> 7  2013     1     1     558             600          -2     924
#> 8  2013     1     1     558             600          -2     923
#> 9  2013     1     1     559             559           0     702
#> 10 2013     1     1     600             600           0     851
#> # ... with 141,135 more rows, and 12 more variables:
#> #   sched_arr_time <int>, arr_delay <dbl>, carrier <chr>,
#> #   flight <int>, tailnum <chr>, origin <chr>, dest <chr>,
#> #   air_time <dbl>, distance <dbl>, hour <dbl>, minute <dbl>,
#> #   time_hour <dtm>
```

# Visually understand the semi-join

## ■ One-to-many:

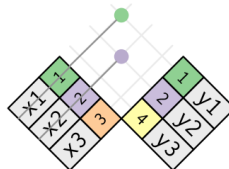


## ■ Many-to-many:



# flights without a match in planes

```
flights %>%  
  anti_join(planes,  
            by = "tailnum") %>%  
  count(tailnum, sort = TRUE)  
#> # A tibble: 722 x 2  
#>   tailnum      n  
#>   <chr>   <int>  
#> 1 <NA>     2512  
#> 2 N725MQ    575  
#> 3 N722MQ    513  
#> 4 N723MQ    507  
#> 5 N713MQ    483  
#> 6 N735MQ    396  
#> 7 NOEGMQ    371  
#> 8 N534MQ    364  
#> 9 N542MQ    363  
#> 10 N531MQ   349  
#> # ... with 712 more rows
```



key	val_x
3	x3

1 Relational data

2 Combining tables

**3 Dates and times**

4 Factors

5 Strings

- Does every year have 365 days?
- Does every day have 24 hours?
- Does every minute have 60 seconds?

- Three types of date/time data:
  - ▶ A **date**.
    - Tibbles print this as `<date>`.
  - ▶ A **time** within a day.
    - Tibbles print this as `<time>`.
  - ▶ A **date-time** is a date plus a time.
    - Uniquely identifies an instant in time (typically to the nearest second).
    - Tibbles print this as `<dtm>`.
    - Elsewhere in R, POSIXct.
- In R:
  - ▶ Focus on dates/date-times because no “native” class for times.
  - ▶ If you need one, look at the **hms** package.
- Use the simplest possible data type satisfying your needs!

- The **lubridate** package:
  - ▶ Makes it easier to work with dates and times in R.
  - ▶ Not part of core tidyverse because only needed when working with dates/times.

```
library(lubridate)
today()
#> [1] "2019-10-25"
now()
#> [1] "2019-10-25 14:19:36 EDT"
```

- Three other (usual) ways to create a date/time:
  - ▶ From a string.
  - ▶ From individual date-time components.
  - ▶ From an existing date/time object (i.e., with `as_datetime(today())` or conversely `as_date(now())`).



```
ymd("2017-01-31")
#> [1] "2017-01-31"
mdy("January 31st, 2017")
#> [1] "2017-01-31"
dmy("31-Jan-2017")
#> [1] "2017-01-31"

ymd_hms("2017-01-31 20:11:59")
#> [1] "2017-01-31 20:11:59 UTC"
mdy_hm("01/31/2017 08:01")
#> [1] "2017-01-31 08:01:00 UTC"
```

## ■ Additionally:

```
ymd(20170131)
#> [1] "2017-01-31"
ymd(20170131, tz = "UTC")
#> [1] "2017-01-31 UTC"
```

# From individual components

```
flights %>%
  select(year, month, day, hour, minute, dep_time) %>%
  mutate(departure = make_datetime(year, month, day, hour, minute))
#> # A tibble: 336,776 x 7
#>   year month   day hour minute dep_time departure
#>   <int> <int> <int> <dbl> <dbl>   <int> <dtm>
#> 1  2013     1     1     5     15     517 2013-01-01 05:15:00
#> 2  2013     1     1     5     29     533 2013-01-01 05:29:00
#> 3  2013     1     1     5     40     542 2013-01-01 05:40:00
#> 4  2013     1     1     5     45     544 2013-01-01 05:45:00
#> 5  2013     1     1     6     0     554 2013-01-01 06:00:00
#> 6  2013     1     1     5     58     554 2013-01-01 05:58:00
#> 7  2013     1     1     6     0     555 2013-01-01 06:00:00
#> 8  2013     1     1     6     0     557 2013-01-01 06:00:00
#> 9  2013     1     1     6     0     557 2013-01-01 06:00:00
#> 10 2013     1     1     6     0     558 2013-01-01 06:00:00
#> # ... with 336,766 more rows
```

- For `dep_time` and others such as `arr_time`:

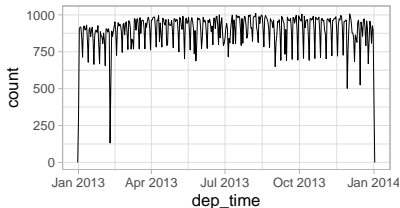
```
make_datetime_100 <- function(year, month, day, time) {
  make_datetime(year, month, day, time %/% 100, time %% 100)
}
```

# From individual components II

```
flights_dt <- flights %>%  
  filter(!is.na(dep_time), !is.na(arr_time)) %>%  
  mutate(dep_time = make_datetime_100(year, month, day, dep_time),  
         arr_time = make_datetime_100(year, month, day, arr_time)) %>%  
  select(origin, dest, ends_with("delay"), ends_with("time"))
```

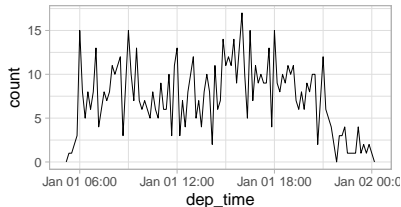
```
flights_dt %>%  
  ggplot(aes(dep_time)) +  
    geom_freqpoly(binwidth = 86400) + # 86400s=1d  
    ggtitle("Departures in a year")  
#
```

Departures in a year



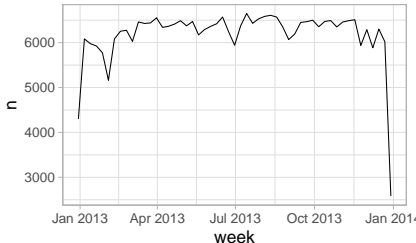
```
flights_dt %>%  
  filter(dep_time < ymd(20130102)) %>%  
  ggplot(aes(dep_time)) +  
    geom_freqpoly(binwidth = 600) + # 600s=10mn  
    ggtitle("Departures on January 1st")
```

Departures on January 1st



- Rounding:
  - ▶ `floor_date()` rounds down.
  - ▶ `round_date()` rounds to.
  - ▶ `ceiling_date()` rounds up.
- Takes a vector of dates to adjust and then the name of the unit:

```
flights_dt %>%  
  count(week = floor_date(dep_time, "week")) %>%  
  ggplot(aes(week, n)) +  
  geom_line()
```



## ■ Getting the components:

```
datetime <- ymd_hms("2016-07-08 12:34:56")  
c(year(datetime), month(datetime), mday(datetime),  
  yday(datetime), wday(datetime))  
#> [1] 2016      7      8    190      6
```

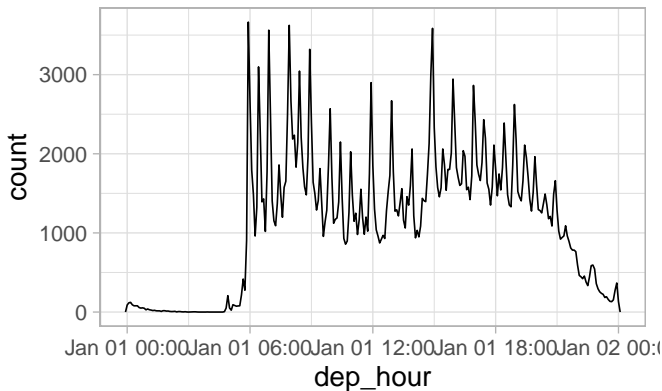
## ■ Setting the components:

```
year(datetime) <- 2020  
datetime  
#> [1] "2020-07-08 12:34:56 UTC"  
month(datetime) <- 01  
datetime  
#> [1] "2020-01-08 12:34:56 UTC"  
hour(datetime) <- hour(datetime) + 1  
datetime  
#> [1] "2020-01-08 13:34:56 UTC"
```

## ■ Alternatively, use e.g. `update(datetime, year = 2020)`.

# Flights distribution across the day

```
flights_dt %>%  
  mutate(dep_hour = update(dep_time, yday = 1)) %>%  
  ggplot(aes(dep_hour)) +  
    geom_freqpoly(binwidth = 300)
```



- Goal: to do arithmetic (i.e., subtraction, addition, and division) with dates/times.
- Three classes that represent time spans:
  - ▶ **Durations** (number of seconds).
  - ▶ **Periods** (human units like weeks and months).
  - ▶ **Intervals** (a starting and ending point).

- A **duration** always record a time span in seconds.
- Larger units created at the standard rate.
  - ▶ E.g., 60s/mn, 60mn/h, 24h/d, 7d/w, 365d/y.

```
dseconds(15)
#> [1] "15s"
dminutes(10)
#> [1] "600s (~10 minutes)"
dhours(c(12, 24))
#> [1] "43200s (~12 hours)" "86400s (~1 days)"
ddays(0:5)
#> [1] "0s" "86400s (~1 days)" "172800s (~2 days)"
#> [4] "259200s (~3 days)" "345600s (~4 days)" "432000s (~5 days)"
dweeks(3)
#> [1] "1814400s (~3 weeks)"
dyears(1)
#> [1] "31536000s (~52.14 weeks)"
```



## ■ Add and multiply durations:

```
2 * dyears(1)
#> [1] "63072000s (~2 years)"
dyears(1) + dweeks(12) + dhours(15)
#> [1] "38847600s (~1.23 years)"
```

## ■ Add and subtract durations to and from dates/datetimes:

```
tomorrow <- today() + ddays(1)
last_year <- today() - dyears(1)
```

## ■ What happens here?

```
one_pm <- ymd_hms("2016-03-12 13:00:00", tz = "America/New_York")
one_pm
#> [1] "2016-03-12 13:00:00 EST"
one_pm + ddays(1)
#> [1] "2016-03-13 14:00:00 EDT"
```

- Work with “human” times, like days (no fixed length in secs):

```
one_pm
#> [1] "2016-03-12 13:00:00 EST"
one_pm + days(1)
#> [1] "2016-03-13 13:00:00 EDT"
seconds(15)
#> [1] "15S"
minutes(10)
#> [1] "10M OS"
hours(c(12, 24))
#> [1] "12H OM OS" "24H OM OS"
days(7)
#> [1] "7d OH OM OS"
months(1:3)
#> [1] "1m Od OH OM OS" "2m Od OH OM OS" "3m Od OH OM OS"
weeks(3)
#> [1] "21d OH OM OS"
years(1)
#> [1] "1y Om Od OH OM OS"
```

## ■ Add and multiply periods:

```
10 * (months(6) + days(1))  
#> [1] "60m 10d 0H 0M 0S"  
days(50) + hours(25) + minutes(2)  
#> [1] "50d 25H 2M 0S"
```

## ■ Add periods to dates/datetimes:

```
# A leap year  
ymd("2016-01-01") + dyears(1)  
#> [1] "2016-12-31"  
ymd("2016-01-01") + years(1)  
#> [1] "2017-01-01"  
  
# Daylight Savings Time  
one_pm + ddays(1)  
#> [1] "2016-03-13 14:00:00 EDT"  
one_pm + days(1)  
#> [1] "2016-03-13 13:00:00 EDT"
```

- What should the following code return?

```
years(1) / days(1)
```

- A duration with a starting point:

```
next_year <- today() + years(1)
(today() %--% next_year) / ddays(1)
#> [1] 366
```

	date				date time				duration				period				interval				number			
date	-								-	+			-	+							-	+		
date time					-				-	+			-	+							-	+		
duration	-	+			-	+			-	+	/										-	+	×	/
period	-	+			-	+							-	+							-	+	×	/
interval											/				/									
number	-	+			-	+			-	+	×		-	+	×		-	+	×		-	+	×	/

- Pick the simplest data structure that solves your problem:
  - ▶ If you only care about physical time, use a duration.
  - ▶ If you need to add human times, use a period.
  - ▶ If you need to figure out how long a span is in human units, use an interval.

```
Sys.timezone()
#> [1] "America/New_York"
length(OlsonNames())
#> [1] 607
head(OlsonNames())
#> [1] "Africa/Abidjan"      "Africa/Accra"        "Africa/Addis_Ababa"
#> [4] "Africa/Algiers"     "Africa/Asmara"       "Africa/Asmera"
```

## ■ Same instant, different place:

```
(x1 <- ymd_hms("2015-06-01 12:00:00", tz = "America/New_York"))
#> [1] "2015-06-01 12:00:00 EDT"
(x2 <- ymd_hms("2015-06-01 18:00:00", tz = "Europe/Copenhagen"))
#> [1] "2015-06-01 18:00:00 CEST"
(x3 <- ymd_hms("2015-06-02 04:00:00", tz = "Pacific/Auckland"))
#> [1] "2015-06-02 04:00:00 NZST"
x1 - x2
#> Time difference of 0 secs
x1 - x3
#> Time difference of 0 secs
```

## ■ Note the behavior of 'c()':

```
x4 <- c(x1, x2, x3)
x4
#> [1] "2015-06-01 12:00:00 EDT" "2015-06-01 12:00:00 EDT"
#> [3] "2015-06-01 12:00:00 EDT"
```

## ■ Keep the instant in time:

```
x4a <- with_tz(x4, tzzone = "Australia/Lord_Howe")
x4a
#> [1] "2015-06-02 02:30:00 +1030" "2015-06-02 02:30:00 +1030"
#> [3] "2015-06-02 02:30:00 +1030"
x4a - x4
#> Time differences in secs
#> [1] 0 0 0
```

## ■ Change the instant in time:

```
x4b <- force_tz(x4, tzzone = "Australia/Lord_Howe")
x4b
#> [1] "2015-06-01 12:00:00 +1030" "2015-06-01 12:00:00 +1030"
#> [3] "2015-06-01 12:00:00 +1030"
x4b - x4
#> Time differences in hours
#> [1] -14.5 -14.5 -14.5
```



1 Relational data

2 Combining tables

3 Dates and times

**4 Factors**

5 Strings

- Factors are:
  - ▶ Used to work with categorical variables (i.e., that have a fixed and known set of possible values).
  - ▶ Useful to display character vectors in a non-alphabetical order.
- The **forcats** package:
  - ▶ Range of helpers for working with factors.

```
library(forcats)
```

- Imagine that you have a variable that records month:

```
x1 <- c("Dec", "Apr", "Jan", "Mar")
```

- Using a string to record this variable has two problems:
  - ▶ Twelve possible months and nothing saving you from typos.
  - ▶ It doesn't sort in a useful way.

```
sort(x1)  
#> [1] "Apr" "Dec" "Jan" "Mar"
```

- Start by creating a list of the valid **levels**:

```
month_levels <- c("Jan", "Feb", "Mar", "Apr", "May", "Jun",  
                  "Jul", "Aug", "Sep", "Oct", "Nov", "Dec")
```

- Then create a factor:

```
y1 <- factor(x1, levels = month_levels)  
y1  
#> [1] Dec Apr Jan Mar  
#> Levels: Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec  
sort(y1)  
#> [1] Jan Mar Apr Dec  
#> Levels: Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec  
factor(x1) ## without levels  
#> [1] Dec Apr Jan Mar  
#> Levels: Apr Dec Jan Mar
```

## ■ Notice:

```
x2 <- c("Dec", "Apr", "Jam", "Mar")
y2 <- factor(x2, levels = month_levels)
y2
#> [1] Dec Apr <NA> Mar
#> Levels: Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
```

## ■ Other ordering:

```
factor(x1, levels = unique(x1))
#> [1] Dec Apr Jan Mar
#> Levels: Dec Apr Jan Mar
factor(x1) %>%
  fct_inorder()
#> [1] Dec Apr Jan Mar
#> Levels: Dec Apr Jan Mar
```

## ■ Sample from the General Social Survey:

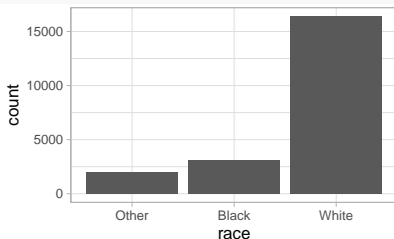
```
gss_cat
#> # A tibble: 21,483 x 9
#>   year marital    age race  rincome partyid relig  denom  tvhours
#>   <int> <fct>    <int> <fct> <fct>    <fct> <fct> <fct>    <int>
#> 1  2000 Never m~    26 White $8000 t~ Ind,nea~ Prote~ South~    12
#> 2  2000 Divorced    48 White $8000 t~ Not str~ Prote~ Bapti~    NA
#> 3  2000 Widowed    67 White Not app~ Indepen~ Prote~ No de~     2
#> 4  2000 Never m~    39 White Not app~ Ind,nea~ Ortho~ Not a~     4
#> 5  2000 Divorced    25 White Not app~ Not str~ None   Not a~     1
#> 6  2000 Married    25 White $20000 ~ Strong ~ Prote~ South~    NA
#> 7  2000 Never m~    36 White $25000 ~ Not str~ Chris~ Not a~     3
#> 8  2000 Divorced    44 White $7000 t~ Ind,nea~ Prote~ Luthe~    NA
#> 9  2000 Married    44 White $25000 ~ Not str~ Prote~ Other     0
#> 10 2000 Married    47 White $25000 ~ Strong ~ Prote~ South~     3
#> # ... with 21,473 more rows
```

## ■ More info with ?gss\_cat.

# See levels of a factor from a tibble

## ■ A barplot:

```
ggplot(gss_cat, aes(race)) +  
  geom_bar()
```

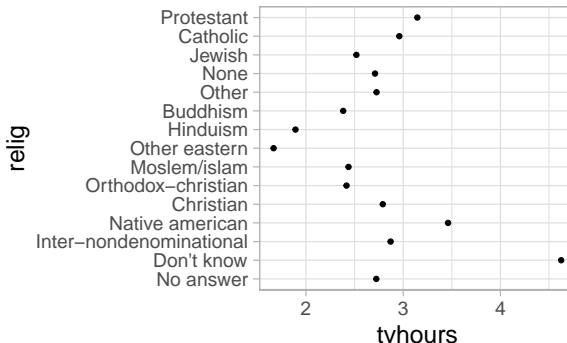


## ■ Or a count:

```
gss_cat %>%  
  count(race)  
  
#> # A tibble: 3 x 2  
#>   race      n  
#>   <fct> <int>  
#> 1 Other  1959  
#> 2 Black  3129  
#> 3 White 16395
```

# What's wrong here?

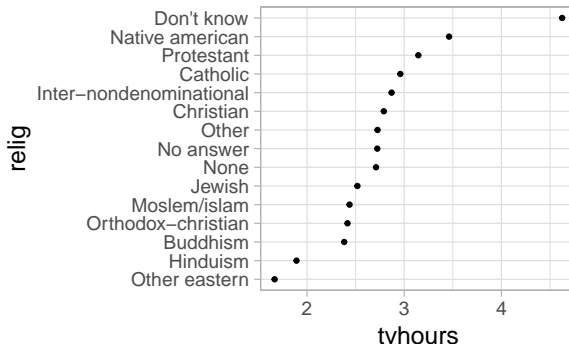
```
relig_summary <- gss_cat %>%  
  group_by(relig) %>%  
  summarize(age = mean(age, na.rm = TRUE),  
            tvhours = mean(tvhours, na.rm = TRUE),  
            n = n())  
  
ggplot(relig_summary, aes(tvhours, relig)) +  
  geom_point()
```





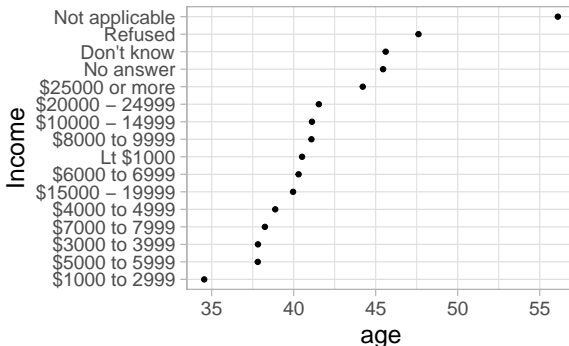
# Modifying factor order

```
relig_summary %>%  
  mutate(relig = fct_reorder(relig, tvhours)) %>%  
  ggplot(aes(tvhours, relig)) +  
  geom_point()
```



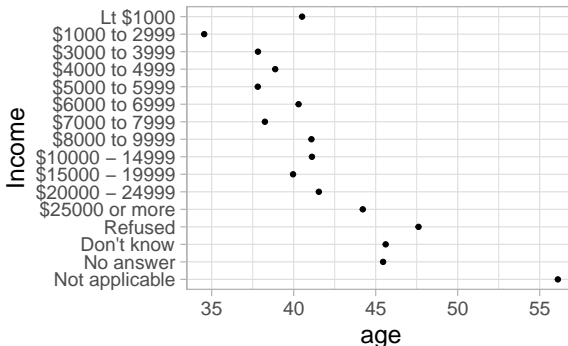
# What's wrong here?

```
rincome_summary <- gss_cat %>%  
  group_by(rincome) %>%  
  summarize(age = mean(age, na.rm = TRUE),  
            tvhours = mean(tvhours, na.rm = TRUE),  
            n = n())  
  
ggplot(rincome_summary, aes(age, fct_reorder(rincome, age))) +  
  geom_point() + ylab("Income")
```



# Modify factor order II

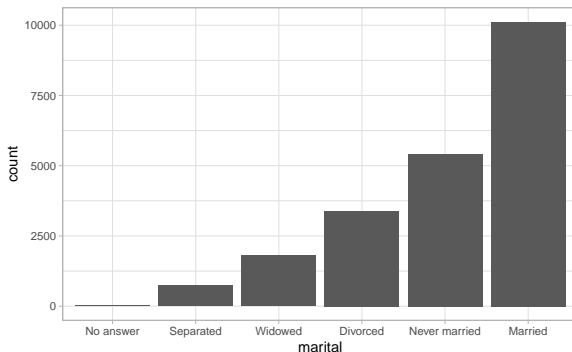
```
ggplot(rincome_summary,  
       aes(age, fct_relevel(rincome, "Not applicable")) +  
       geom_point() +  
       ylab("Income"))
```



- Why do you think the average age for “Not applicable” is so high?

# Modify factor order III

```
gss_cat %>%  
  mutate(marital = marital %>% fct_infreq() %>% fct_rev()) %>%  
  ggplot(aes(marital)) +  
  geom_bar()
```



- More powerful than changing the orders of the levels is changing their values:
  - ▶ To clarify labels for publication.
  - ▶ To collapse levels for high-level displays.

# What's wrong here?

```
gss_cat %>%  
  count(partyid)  
#> # A tibble: 10 x 2  
#>   partyid      n  
#>   <fct>    <int>  
#> 1 No answer      154  
#> 2 Don't know       1  
#> 3 Other party    393  
#> 4 Strong republican 2314  
#> 5 Not str republican 3032  
#> 6 Ind,near rep    1791  
#> 7 Independent    4119  
#> 8 Ind,near dem    2499  
#> 9 Not str democrat 3690  
#> 10 Strong democrat 3490
```

# Modifying factor levels II

```
gss_cat %>%
  mutate(partyid = fct_recode(partyid,
    "Republican, strong" = "Strong republican",
    "Republican, weak" = "Not str republican",
    "Independent, near rep" = "Ind,near rep",
    "Independent, near dem" = "Ind,near dem",
    "Democrat, weak" = "Not str democrat",
    "Democrat, strong" = "Strong democrat")) %>%
  count(partyid)

#> # A tibble: 10 x 2
#>   partyid      n
#>   <fct>    <int>
#> 1 No answer    154
#> 2 Don't know     1
#> 3 Other party   393
#> 4 Republican, strong 2314
#> 5 Republican, weak  3032
#> 6 Independent, near rep 1791
#> 7 Independent    4119
#> 8 Independent, near dem 2499
#> 9 Democrat, weak  3690
#> 10 Democrat, strong 3490
```

# Collapsing factors

```
gss_cat %>%
  mutate(partyid = fct_recode(partyid,
    "Republican, strong" = "Strong republican",
    "Republican, weak" = "Not str republican",
    "Independent, near rep" = "Ind,near rep",
    "Independent, near dem" = "Ind,near dem",
    "Democrat, weak" = "Not str democrat",
    "Democrat, strong" = "Strong democrat",
    "Other" = "No answer",
    "Other" = "Don't know",
    "Other" = "Other party" )) %>%
  count(partyid)

#> # A tibble: 8 x 2
#>   partyid          n
#>   <fct>          <int>
#> 1 Other          548
#> 2 Republican, strong 2314
#> 3 Republican, weak 3032
#> 4 Independent, near rep 1791
#> 5 Independent      4119
#> 6 Independent, near dem 2499
#> 7 Democrat, weak 3690
#> 8 Democrat, strong 3490
```



```
gss_cat %>%  
  mutate(partyid = fct_collapse(partyid,  
    other = c("No answer", "Don't know", "Other party"),  
    rep = c("Strong republican", "Not str republican"),  
    ind = c("Ind,near rep", "Independent", "Ind,near dem"),  
    dem = c("Not str democrat", "Strong democrat")  
  ) %>%  
  count(partyid)  
#> # A tibble: 4 x 2  
#>   partyid      n  
#>   <fct>   <int>  
#> 1 other      548  
#> 2 rep       5346  
#> 3 ind       8409  
#> 4 dem      7180
```

# Collapsing factor III

```
gss_cat %>%  
  mutate(relig = fct_lump(relig)) %>%  
  count(relig)  
#> # A tibble: 2 x 2  
#>   relig      n  
#>   <fct>    <int>  
#> 1 Protestant 10846  
#> 2 Other      10637  
  
gss_cat %>%  
  mutate(relig = fct_lump(relig, n = 3)) %>%  
  count(relig, sort = TRUE)  
#> # A tibble: 4 x 2  
#>   relig      n  
#>   <fct>    <int>  
#> 1 Protestant 10846  
#> 2 Catholic    5124  
#> 3 None        3523  
#> 4 Other       1990
```

1 Relational data

2 Combining tables

3 Dates and times

4 Factors

**5 Strings**

```
library(stringr) # package for string manipulation

# To create strings
string1 <- "This is a string"
string2 <- 'To get a "quote" inside a string, use single quotes'
```

## ■ Backslash as escape character:

```
double_quote <- "\"\" # or '\"'
single_quote <- '\'' # or '\"'
```

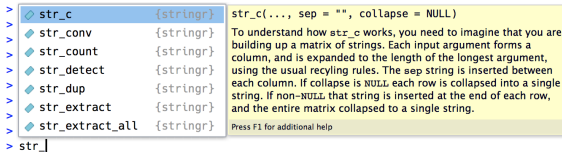
## ■ The printed representation is not the string itself:

```
x <- c("\"", "\\")
x
#> [1] "\" " \" \"
writeLines(x)
#> "
#> \
```

- Special characters:
  - ▶ Use `"\n"`, for newline, or `"\t"`, for tab.
  - ▶ Complete list by requesting help on `" (? ' ' , or ? ' ' )"`
- Other usefuls things:

```
(x <- "\u00b5") # Non-English characters
#> [1] "µ"
c("one", "two", "three") # Character vectors
#> [1] "one" "two" "three"
str_length(c("a", "R for data science", NA)) # String length
#> [1] 1 18 NA
```

- stringr autocomplete:



The screenshot shows the RStudio interface with a list of stringr functions on the left and their descriptions on the right. The functions listed are: `str_c`, `str_conv`, `str_count`, `str_detect`, `str_dup`, `str_extract`, and `str_extract_all`. The description for `str_c` explains how it works by building a matrix of strings and collapsing it into a single string. It also mentions that non-NULL strings are inserted at the end of each row, and the entire matrix is collapsed into a single string. A note at the bottom of the description says "Press F1 for additional help".

Function	Class
<code>str_c</code>	<code>{stringr}</code>
<code>str_conv</code>	<code>{stringr}</code>
<code>str_count</code>	<code>{stringr}</code>
<code>str_detect</code>	<code>{stringr}</code>
<code>str_dup</code>	<code>{stringr}</code>
<code>str_extract</code>	<code>{stringr}</code>
<code>str_extract_all</code>	<code>{stringr}</code>

`str_c(..., sep = "", collapse = NULL)`

To understand how `str_c` works, you need to imagine that you are building up a matrix of strings. Each input argument forms a column, and is expanded to the length of the longest argument, using the usual recycling rules. The `sep` string is inserted between each column. If `collapse` is `NULL` each row is collapsed into a single string. If non-`NULL` that string is inserted at the end of each row, and the entire matrix collapsed to a single string.

Press F1 for additional help

## ■ Combining strings:

```
str_c("x", "y")  
#> [1] "xy"  
str_c("x", "y", "z")  
#> [1] "xyz"  
str_c("x", "y", sep = ", ")  
#> [1] "x, y"
```

## ■ Missing values:

```
x <- c("abc", NA)  
str_c("|-", x, "-|")  
#> [1] "|-abc-|" NA  
str_c("|-", str_replace_na(x), "-|")  
#> [1] "|-abc-|" "|-NA-|"
```

## ■ Recycling:

```
str_c("prefix-", c("a", "b", "c"), "-suffix")  
#> [1] "prefix-a-suffix" "prefix-b-suffix" "prefix-c-suffix"
```

## ■ Collapsing a vector of strings:

```
str_c(c("x", "y", "z"), collapse = ", ")  
#> [1] "x, y, z"
```

```
x <- c("Apple", "Banana", "Pear")
str_sub(x, 1, 3)
#> [1] "App" "Ban" "Pea"
str_sub(x, -3, -1)
#> [1] "ple" "ana" "ear"
str_sub("a", 1, 5)
#> [1] "a"
str_sub(x, 1, 1) <- str_to_lower(str_sub(x, 1, 1))
x
#> [1] "apple" "banana" "pear"
```

- See also `str_to_upper()` or `str_to_title()`.

```
# Turkish has two i's: with and without a dot, and it  
# has a different rule for capitalising them:  
str_to_upper(c("i", "ı"))  
#> [1] "I" "I"  
str_to_upper(c("i", "ı"), locale = "tr")  
#> [1] "İ" "I"
```

## ■ The locale:

- ▶ An ISO 639 language code, which is a **two or three letter abbreviation**
- ▶ If blank, R uses the current locale, as provided by your operating system.



*Some people, when confronted with a problem, think “I know, I’ll use regular expressions.” Now, they have two problems. — Jamie Zawinski*

- A language that allows you to describe patterns in strings.
- Allows you for instance to:
  - ▶ Determine which strings match a pattern.
  - ▶ Find the positions of matches.
  - ▶ Extract the content of matches.
  - ▶ Replace matches with new values.
  - ▶ Split a string based on a match.
- Read the chapter on strings from the book!

- The simplest patterns match exact strings:

```
x <- c("apple", "banana", "pear")  
str_view(x, "an")
```

apple

banana

pear

- Next step is ., which matches any character (except a newline):

```
str_view(x, ".a.")
```

apple

banana

pear

- If "." matches any character, how to match the character "."?

- If “.” matches any character, how to match the character “.”?
  - ▶ Need to use an “escape” (like string, a backslash \).
  - ▶ So to match an ., need the regexp \.
  - ▶ But \ is also an escape symbol in strings.
  - ▶ So to create the regexp \., use the string "\\.”.

```
# To create the regexp, we need \\
dot <- "\\.”
# But the expression itself only contains one:
writeLines(dot)
#> \.
# And this tells R to look for an explicit .
str_view(c("abc", "a.c", "bef"), "a\\.c")
```

abc

a.c

bef

- If `\` is an escape character, how do you match a literal `\`?
  - ▶ Need to escape it, i.e. create the regexp `\\`.
  - ▶ To create that regexp with a string, which also needs to escape `\`, need to write `"\\\\"`
  - ▶ I.e., need four backslashes to match one!

```
x <- "a\\b"  
writeLines(x)  
#> a\b  
str_view(x, "\\")
```

a\b

- By default, regexps match any part of a string.
- Often useful to *anchor* the regexp:
  - ▶ `^` to match the start of the string.
  - ▶ `$` to match the end of the string.

```
x <- c("apple", "banana", "pear")
```

```
str_view(x, "^a")
```

apple

banana

pear

```
str_view(x, "a$")
```

apple

banana

pear

- To remember, [Evan Misshula's mnemonic](#): if you begin with power (`^`), you end up with money (`$`).

- To force a regexp to only match a complete string, anchor it with both `^` and `$`:

```
x <- c("apple pie", "apple", "apple cake")
```

```
str_view(x, "apple")
```

```
apple pie  
apple  
apple cake
```

```
str_view(x, "^apple$")
```

```
apple pie  
apple  
apple cake
```

- Some special patterns match more than one character:
  - ▶ Already seen `.`, which matches any character apart from a newline.
  - ▶ Two other useful tools:
    - `\d`: matches any digit.
    - `\s`: matches any whitespace (e.g. space, tab, newline).
  - ▶ To create a regexp containing `\d` or `\s`:
    - Need to escape the `\` for the string.
    - So type `"\\d"` or `"\\s"`.
- Thw other two tools are:
  - ▶ **Character classes**
    - `[abc]`: matches a, b, or c.
    - `[^abc]`: matches anything except a, b, or c.
  - ▶ **Alternatives**
    - `abc|d..f`: matches either "abc", or "deaf".

- Can be used as an alternative to backslash escapes.

```
str_view(c("abc",  
           "a.c",  
           "a*c",  
           "a c"),  
         "a[.]c")
```

abc

a.c

a\*c

a c

```
str_view(c("abc",  
           "a.c",  
           "a*c",  
           "a c"),  
         ".[*]c")
```

abc

a.c

a\*c

a c

```
str_view(c("abc",  
           "a.c",  
           "a*c",  
           "a c"),  
         "a[ ]")
```

abc

a.c

a\*c

a c

- Used to pick between one or more alternative patterns.
- Works for most regex metacharacters: \$ . | ? \* + ( ) [ {.
- But some have special meaning even inside a character class.
  - ▶ Must be handled with backslash escapes: ] \ ^ and -.



- Note that the precedence for `|` is low:
  - ▶ `abc|xyz`: matches `abc` or `xyz`, not `abcyz` or `abxyz`.
- Same as mathematical expressions: if it gets confusing, use parentheses.

```
str_view(c("grey", "gray"), "gr(e|a)y")
```

grey

gray

- To control how many times a pattern matches:

- ▶ `?:` 0 or 1.
- ▶ `+:` 1 or more.
- ▶ `*:` 0 or more.

```
# 1888 is the longest year in Roman numerals  
x <- "MDCCCLXXXVIII"
```

```
str_view(x, "CC?")
```

MD**CC**CLXXXVIII

```
str_view(x, "CC+")
```

MD**CCCL**XXXVIII

```
str_view(x, 'C[LX]+')
```

MDCC**CL**XXXVIII

- The precedence of these operators is high:
  - ▶ `colou?r`: matches either US or British spellings.
  - ▶ Most uses will need parentheses, like `bana(na)+`.

■ To specify the number of matches precisely:

- ▶ `{n}`: exactly n.
- ▶ `{n,}`: n or more.
- ▶ `{,m}`: at most m.
- ▶ `{n,m}`: between n and m.

```
str_view(x, "C{2}")
```

MDCCCLXXXVIII

```
str_view(x, "C{2,}")
```

MDCCLXXXVIII

```
str_view(x, "C{2,3}")
```

MDCCLXXXVIII

- Earlier: parentheses as a way to disambiguate complex expressions.
- But parentheses also create a *numbered* capturing group.
- A capturing group stores *the part of the string* matched by the part of the regexp inside the parentheses.
- Refer to the same text as previously matched by a capturing group with *backreferences*, like `\1`, `\2` etc.

```
str_view(fruit, "(..)\1", match = TRUE)
```

```
banana  
coconut  
cucumber  
jujube  
papaya  
salal berry
```

- Cool applications in chapter 14.4!