

Relational Data

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Learning Objectives

- What is relational data.
- `inner_join()`, `left_join()`, `right_join()`, `full_join()`, `semi_join()`, `anti_join()`.
- SQL.
- Chapter 13 of [RDS](#).
- [Data Transformation Cheatsheet](#).

Relational Data

- Load the tidyverse

```
library(tidyverse)
```

- Many datasets have more than two data frames.
- These data frames are often connected (rows in one correspond to rows in another)
- Consider the data in the `nycflights13` package.

```
library(nycflights13)
```

– `airlines`: Airline names.

```
data("airlines")
head(airlines)
```

```
## # A tibble: 6 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.
```

– `airports`: Airport metadata

```
data("airports")
head(airports)
```

```
## # A tibble: 6 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/New~
```

```
## 2 06A Moton Field Municipal A~ 32.5 -85.7 264 -6 A America/Chi~
## 3 06C Schaumburg Regional 42.0 -88.1 801 -6 A America/Chi~
## 4 06N Randall Airport 41.4 -74.4 523 -5 A America/New~
## 5 09J Jekyll Island Airport 31.1 -81.4 11 -5 A America/New~
## 6 0A9 Elizabethton Municipal ~ 36.4 -82.2 1593 -5 A America/New~
```

– planes: Plane metadata.

```
data("planes")
head(planes)
```

```
## # A tibble: 6 x 9
##   tailnum year type      manufacturer model engines seats speed engine
##   <chr>   <int> <chr>      <chr>      <chr>   <int> <int> <int> <chr>
## 1 N10156 2004 Fixed win~ EMBRAER     EMB-1~      2    55    NA Turbo~
## 2 N102UW 1998 Fixed win~ AIRBUS INDUST~ A320~      2   182    NA Turbo~
## 3 N103US 1999 Fixed win~ AIRBUS INDUST~ A320~      2   182    NA Turbo~
## 4 N104UW 1999 Fixed win~ AIRBUS INDUST~ A320~      2   182    NA Turbo~
## 5 N10575 2002 Fixed win~ EMBRAER     EMB-1~      2    55    NA Turbo~
## 6 N105UW 1999 Fixed win~ AIRBUS INDUST~ A320~      2   182    NA Turbo~
```

– weather: Hourly weather data

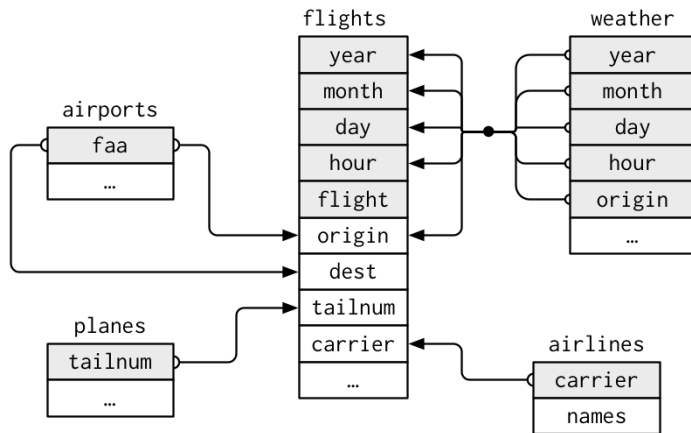
```
data("weather")
head(weather)
```

```
## # A tibble: 6 x 15
##   origin year month   day hour temp dewp humid wind_dir wind_speed
##   <chr>   <dbl> <dbl> <int> <int> <dbl> <dbl> <dbl>   <dbl>   <dbl>
## 1 EWR    2013     1     1     1 39.0 26.1 59.4    270    10.4
## 2 EWR    2013     1     1     2 39.0 27.0 61.6    250     8.06
## 3 EWR    2013     1     1     3 39.0 28.0 64.4    240    11.5
## 4 EWR    2013     1     1     4 39.9 28.0 62.2    250    12.7
## 5 EWR    2013     1     1     5 39.0 28.0 64.4    260    12.7
## 6 EWR    2013     1     1     6 37.9 28.0 67.2    240    11.5
## # ... with 5 more variables: wind_gust <dbl>, precip <dbl>,
## #   pressure <dbl>, visib <dbl>, time_hour <dtm>
```

– flights: Flights data

```
data("flights")
head(flights)
```

```
## # A tibble: 6 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
## # ... with 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>
```



- For nycflights13:
 - **flights** connects to **planes** via a single variable, **tailnum**.
 - **flights** connects to **airlines** through the **carrier** variable.
 - **flights** connects to **airports** in two ways: via the **origin** and **dest** variables.
 - **flights** connects to **weather** via **origin** (the location), and **year**, **month**, **day** and **hour** (the time).
- Variables used to connect a pair of data frames are called **keys**.
- **Primary key**: Identifies rows in its own table.
- **Foreign key**: Identifies rows in another table.
- *Example*: `planes$tailnum` is a primary key because it uniquely identifies rows in **planes**.

```
planes %>%
  group_by(tailnum) %>%
  count() %>%
  filter(n > 1)
```

```
## # A tibble: 0 x 2
## # Groups:   tailnum [0]
## # ... with 2 variables: tailnum <chr>, n <int>
```

- *Example*: `flights$tailnum` is a foreign key because it uniquely identifies rows in **planes**. There are multiple rows with the same **tailnum** in **flights**, so `flights$tailnum` is *not* a primary key.

```
flights %>%
  group_by(tailnum) %>%
  count() %>%
  filter(n > 1)
```

```
## # A tibble: 3,873 x 2
## # Groups:   tailnum [3,873]
##   tailnum      n
##   <chr>    <int>
## 1 <NA>     2512
## 2 D942DN      4
```

```
## 3 NOEGMQ      371
## 4 N10156      153
## 5 N102UW       48
## 6 N103US       46
## 7 N104UW       47
## 8 N10575      289
## 9 N105UW       45
## 10 N107US      41
## # ... with 3,863 more rows
```

- *Example:* `weather$origin` is *part* of the primary key for `weather` (along with `year`, `month`, `day`, and `hour`) and a foreign key for `airports` (`weather$origin` is connected to `airports$faa`).
- If a table lacks a primary key (like `flights`) then you can add one with `mutate()` and `row_number()`.

```
flights %>%
  mutate(row = row_number()) %>%
  select(row, everything())
```

```
## # A tibble: 336,776 x 20
##   row year month day dep_time sched_dep_time dep_delay arr_time
##   <int> <int> <int> <int>   <int>         <int>      <dbl>   <int>
## 1     1   2013     1     1     517             515         2     830
## 2     2   2013     1     1     533             529         4     850
## 3     3   2013     1     1     542             540         2     923
## 4     4   2013     1     1     544             545        -1    1004
## 5     5   2013     1     1     554             600        -6     812
## 6     6   2013     1     1     554             558        -4     740
## 7     7   2013     1     1     555             600        -5     913
## 8     8   2013     1     1     557             600        -3     709
## 9     9   2013     1     1     557             600        -3     838
## 10    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>
```

- **Exercise** ([RDS 13.3.1.2](#)): Identify the primary keys in the following data frames.
 - `Lahman::Batting`,
 - `babynames::babynames`,
 - `nasaweather::atmos`,
 - `fueleconomy::vehicles`,
 - `ggplot2::diamonds`.

(You might need to install some packages and read some documentation.)

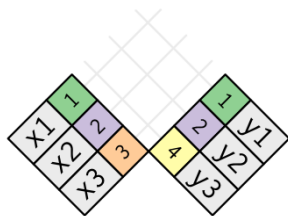
Join Set-Up

- Suppose we have the following two data frames

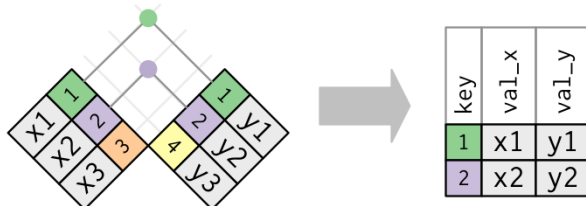
x		y	
1	x1	1	y1
2	x2	2	y2
3	x3	4	y3

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

- A join connects rows of x to rows of y.

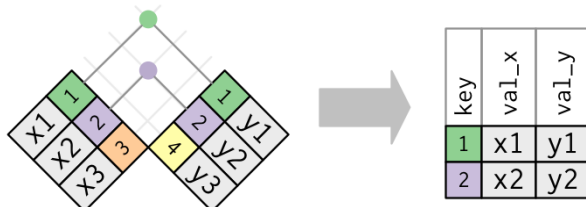


- E.g. match row 1 of x with row 1 of y, and row 2 of x with row 2 of y.



Inner Join

- `inner_join(x, y)` matches the rows of x with rows of y only when their keys are equal.



```
inner_join(x, y, by = "key")
```

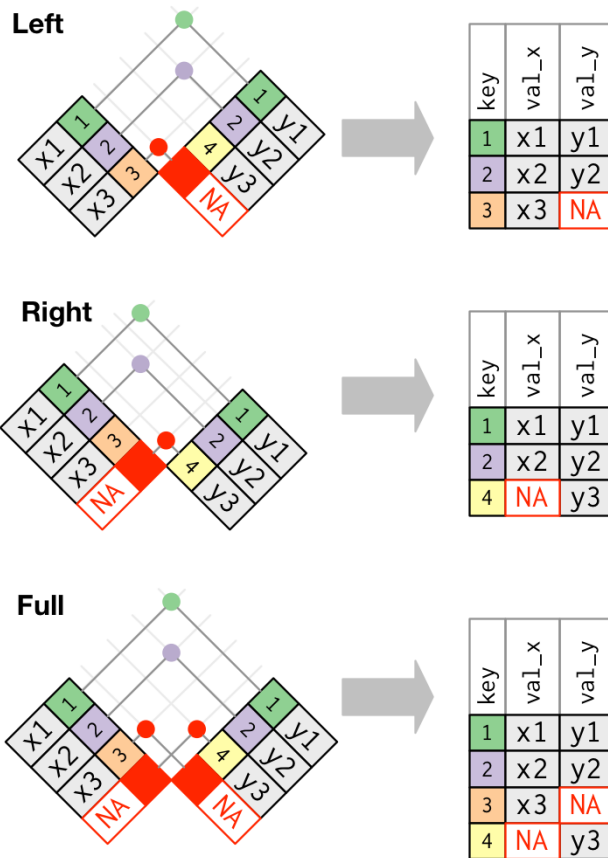
```
## # A tibble: 2 x 3
##   key val_x val_y
```

```
##      <dbl> <chr> <chr>
## 1         1 x1     y1
## 2         2 x2     y2
```

- Keeps all rows that appear in *both* data frames.
- **Exercise:** Select all flights that use a plane where you have some annotation.

Outer Join

- Keeps all rows that appear in *at least one* data frame.



- `left_join(x, y)` keeps all rows of `x`.

```
left_join(x, y, by = "key")
```

```
## # A tibble: 3 x 3
##   key val_x val_y
##   <dbl> <chr> <chr>
## 1     1 x1     y1
## 2     2 x2     y2
## 3     3 x3     <NA>
```

- `left_join()` is by far the most common joiner, and you should always use this unless you have a good reason not to.

- `right_join(x, y)` keeps all rows of `y`.

```
right_join(x, y, by = "key")
```

```
## # A tibble: 3 x 3
##   key val_x val_y
##   <dbl> <chr> <chr>
## 1     1  x1    y1
## 2     2  x2    y2
## 3     4 <NA>   y3
```

- `full_join(x, y)` keeps all rows of both.

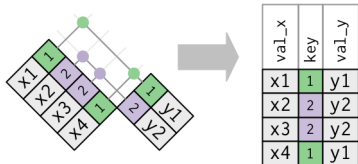
```
full_join(x, y, by = "key")
```

```
## # A tibble: 4 x 3
##   key val_x val_y
##   <dbl> <chr> <chr>
## 1     1  x1    y1
## 2     2  x2    y2
## 3     3  x3    <NA>
## 4     4 <NA>   y3
```

- **Exercise:** Add the full airline names to the `flights` data frame.

Duplicate Keys

- If you have duplicate keys in one table, then the rows from the data frame where there is no duplication are copied multiple times in the new data frame.



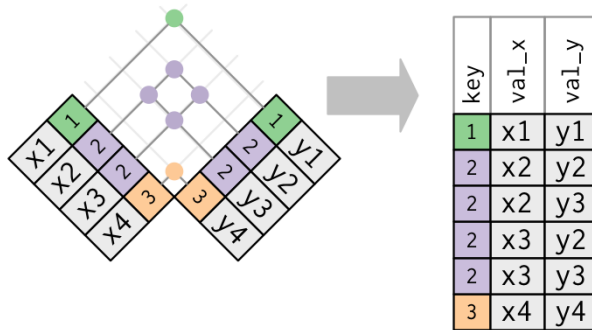
(useful for adding summary data to a table)

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

left_join(x_mult, 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
```

- If you have duplicate keys in both (usually a mistake), then you get every possible combination of the values in x and y at the key values where there are duplications.



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

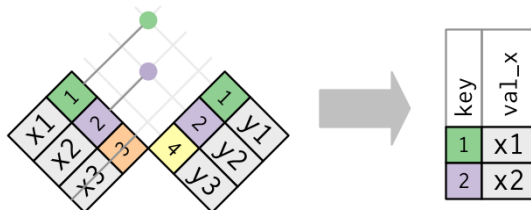
left_join(x_mult, y_mult, by = "key")
```

```
## # A tibble: 8 x 3
##   key val_x val_y
##   <dbl> <chr> <chr>
## 1     1 x1    y1
## 2     1 x1    y4
## 3     2 x2    y2
## 4     2 x2    y3
## 5     2 x3    y2
## 6     2 x3    y3
## 7     1 x4    y1
## 8     1 x4    y4
```

- Exercise:** In the previous two exercises, we had some duplicate keys. For each exercise, which data frame had the duplicate keys?
- Exercise:** Is there a relationship between the age of a plane and its delays?

Filtering Joins

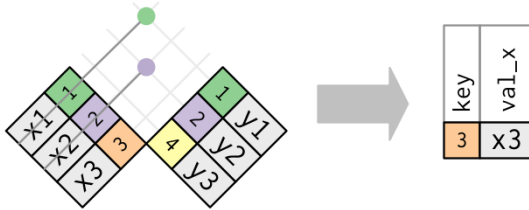
- `semi_join()` keeps all of the rows in x that have a match in y (but don't add the variables of y to x).




```
semi_join(x, y, by = "key")
```

```
## # A tibble: 2 x 2
##   key val_x
##   <dbl> <chr>
## 1     1 x1
## 2     2 x2
```

- `anti_join()` drops all of the rows in `x` that have a match in `y` (but don't add the variables of `y` to `x`).



```
anti_join(x, y, by = "key")
```

```
## # A tibble: 1 x 2
##   key val_x
##   <dbl> <chr>
## 1     3 x3
```

- **Exercise:** Find the 10 days of the year that have the highest median departure delay, then select all flights from those 10 days.

Other Key Names

- If the primary and foreign keys do not match, you need to specify that using a named vector as `left_join(x, y, by = c("a" = "b"))`, where `a` is the key in `x` and `b` is the key in `y`.

```
left_join(flights, airports, by = c("origin" = "faa"))
```

```
## # A tibble: 336,776 x 26
##   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 19 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>, name <chr>, lat <dbl>, lon <dbl>,
## #   alt <int>, tz <dbl>, dst <chr>, tzone <chr>
```

- If you have multiple variables acting as the key, you need the `by` argument to be a vector.

```
left_join(flights, weather, by = c("origin", "year", "month", "day", "hour"))
```

```
## # A tibble: 336,776 x 29
##   year month   day dep_time sched_dep_time dep_delay arr_time
##   <dbl> <dbl> <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 22 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.x <dtm>, temp <dbl>, dewp <dbl>, humid <dbl>,
## #   wind_dir <dbl>, wind_speed <dbl>, wind_gust <dbl>, precip <dbl>,
## #   pressure <dbl>, visib <dbl>, time_hour.y <dtm>
```