# Lists in R

Data structure : a structure, usually with a specific class, that holds data.
eg vector, matrix, array, list, tibble

We are already familiar somewhat with vectors

Vectors are a type of datastructure.

```
fib ← c(1, 2, 3, 5, 8, 13)
```

all values in the list have the same class

class(fib) is ?

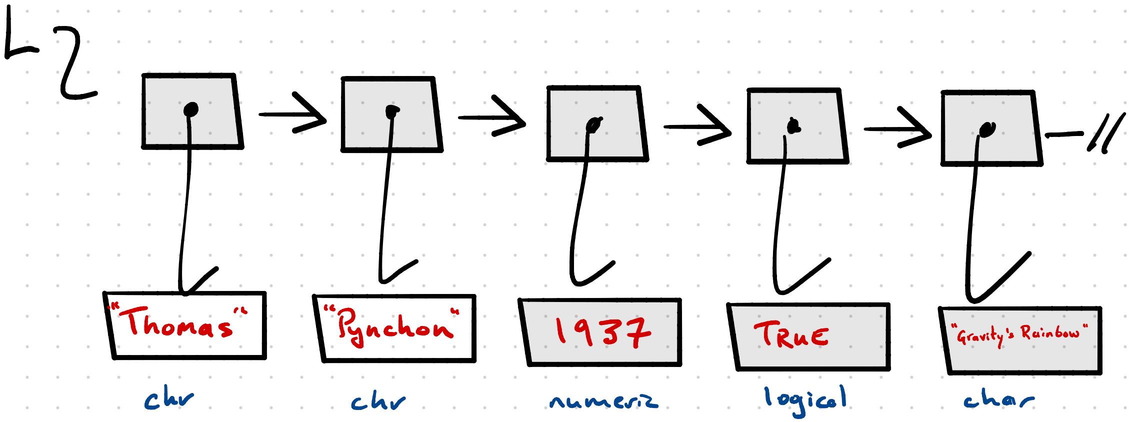
```
she_loves_me_she_loves_me_not ←
        c(TRUE, FALSE, TRUE, FALSE, TRUE)

word_on_street ← c("I", "am", "the", "king")
```

Vectors are very important in R.
Think of one column (variable) in a tibble.

Lists are more general, more flexible.

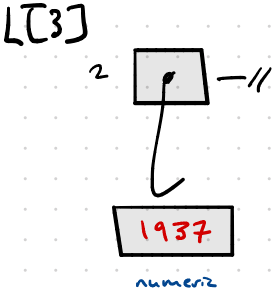
Lists are another type of data structure.

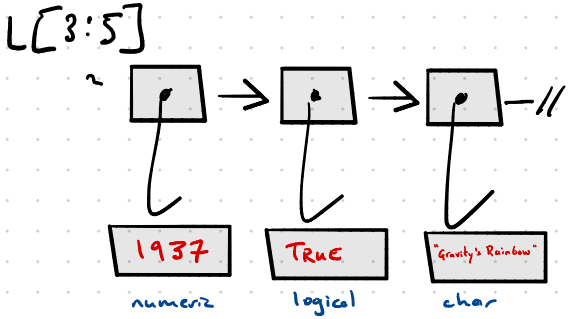
L ← list("Thomas", "Pynchon", 1937,
TRUE, "Gravity's Rainbow")



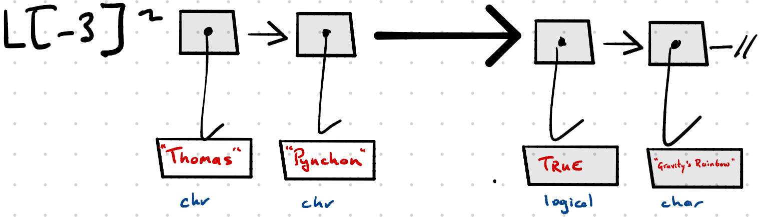
class(L); length(L); names(L)

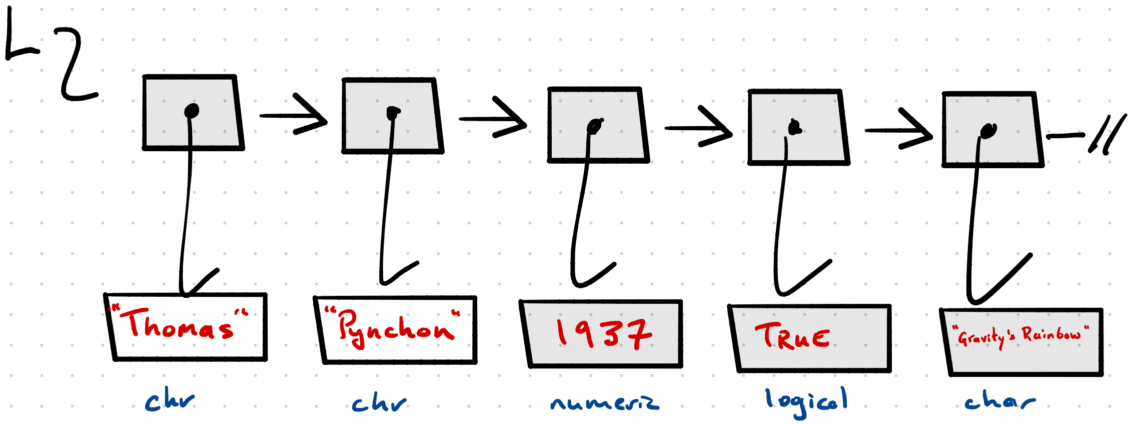
list 5 NULL



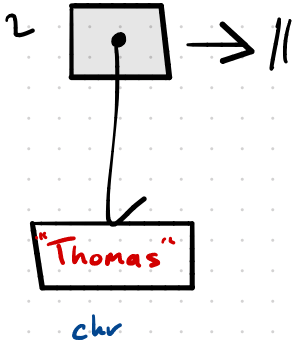


class(L[-3])
= ???



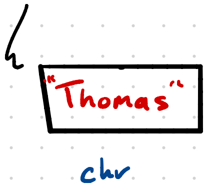


L[1]



THIS IS STILL A LIST (WITH JUST ONE ITEM)

L[[1]]



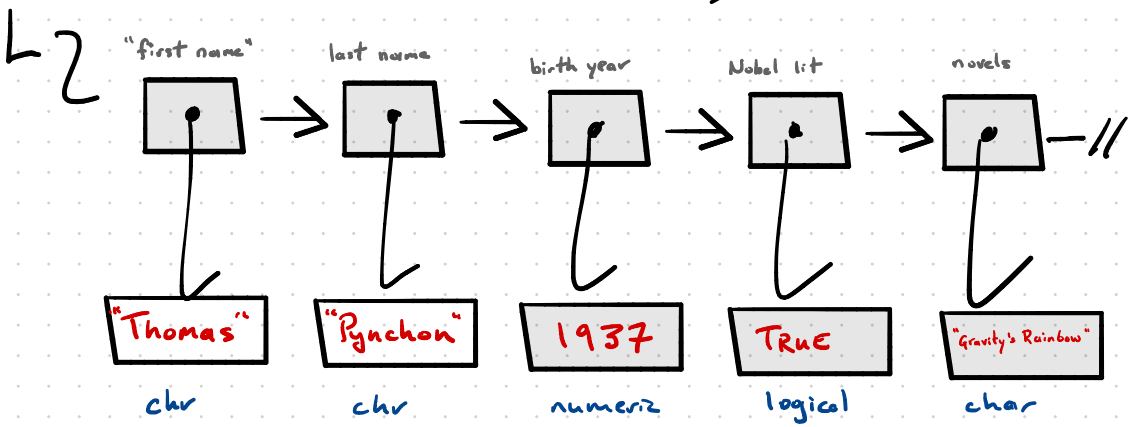
THIS IS THE VALUE IN THE LIST "Thomas" of class chr.

L[[1:3]] ?

L[[1]]
L[[2]]
L[[3]]

# Naming Elements of Lists

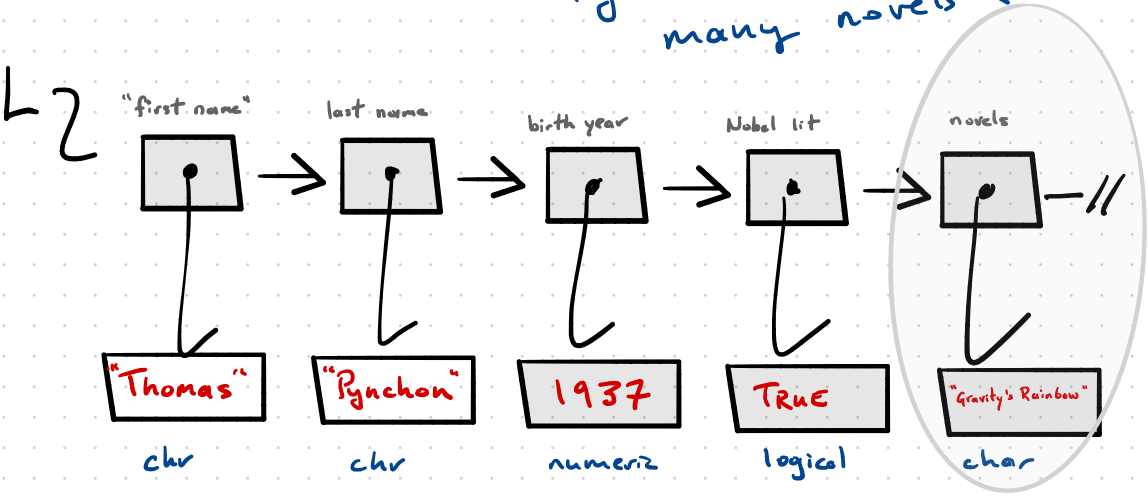
```
names(L) <- c("first name", "last name", "birth year", "Nobel Lit",
              "novels")
```



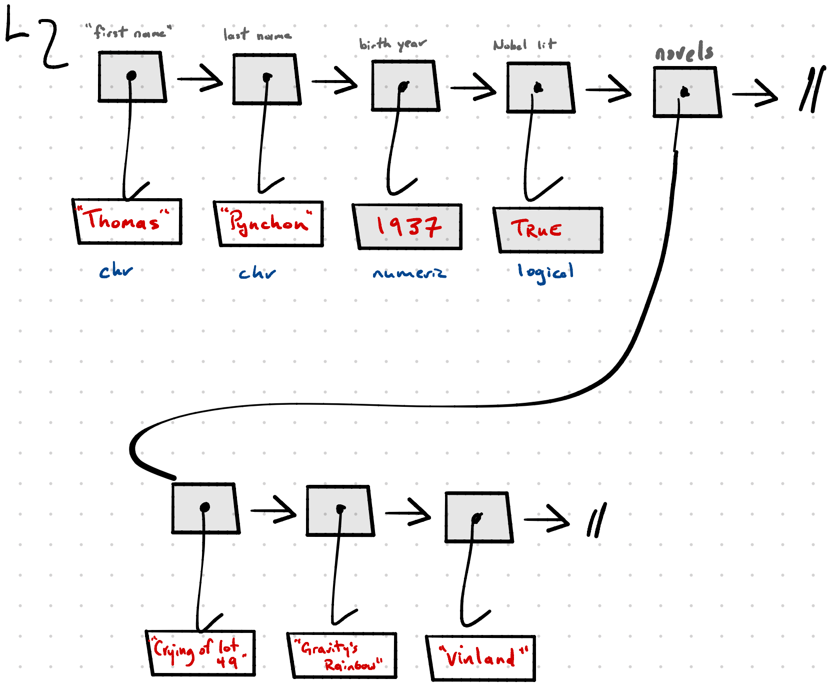
L$"birth year"     same as     L[[3]]

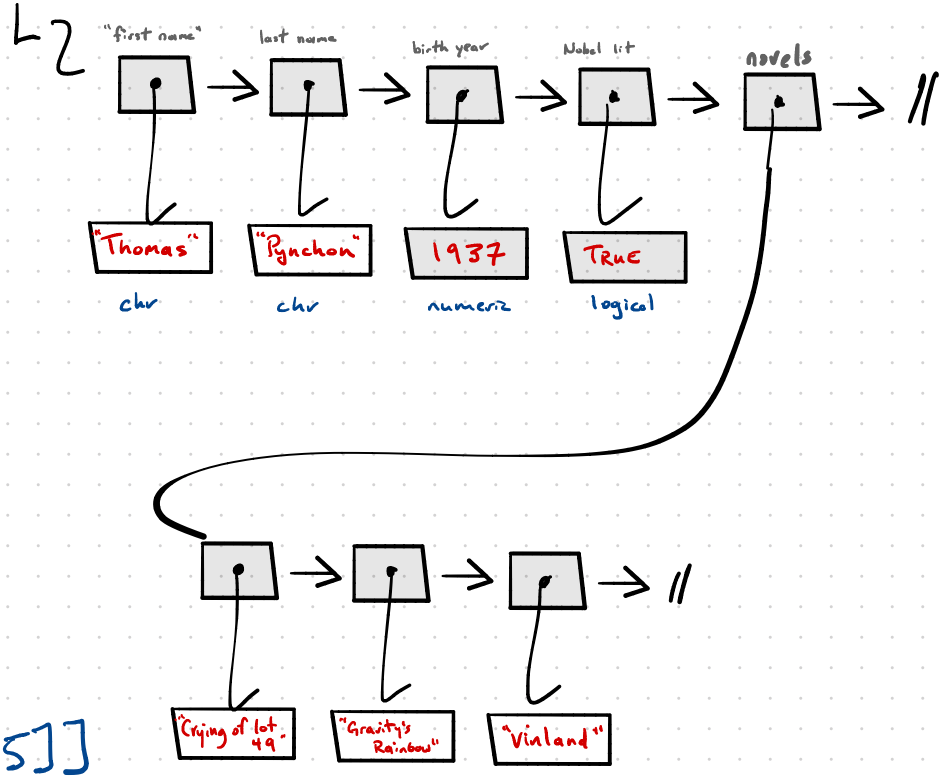
L$"novels"     same as     L[[5]]

Pynchon has written many novels ?



Lists can even contain lists.

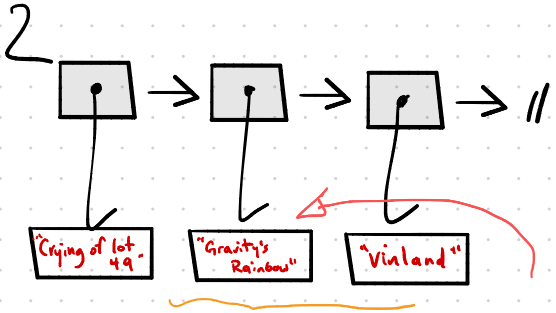




L[[5]]

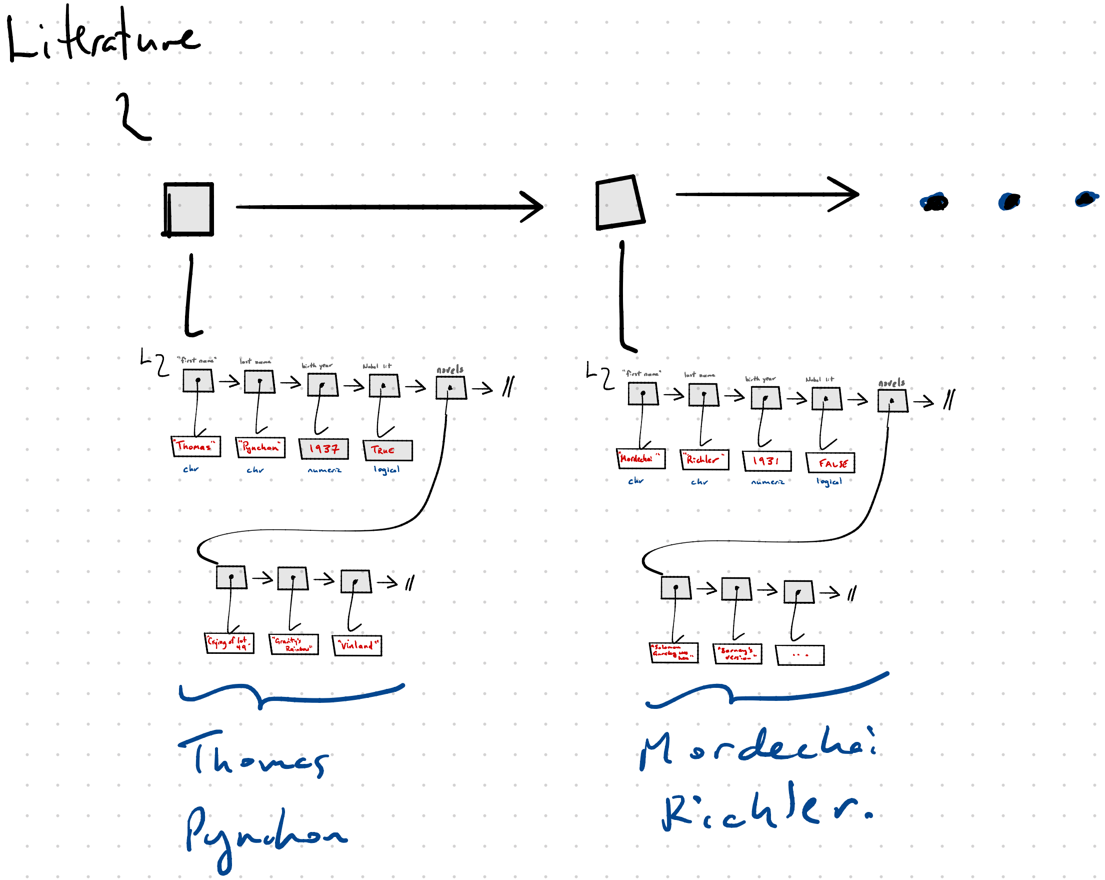
L$novels

L$"novels" ?



L$novels[2:3] ?

L$novels[[2]] ?



DAVID SANKOFF

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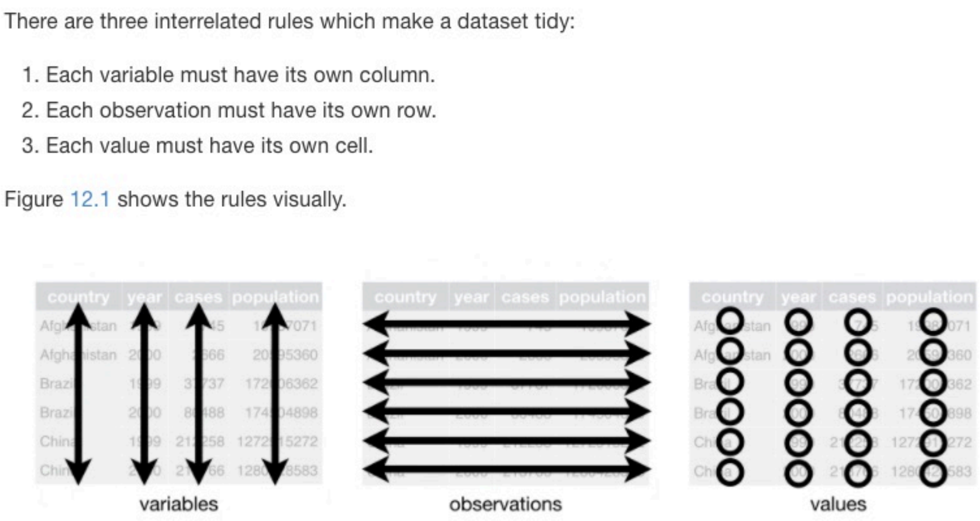
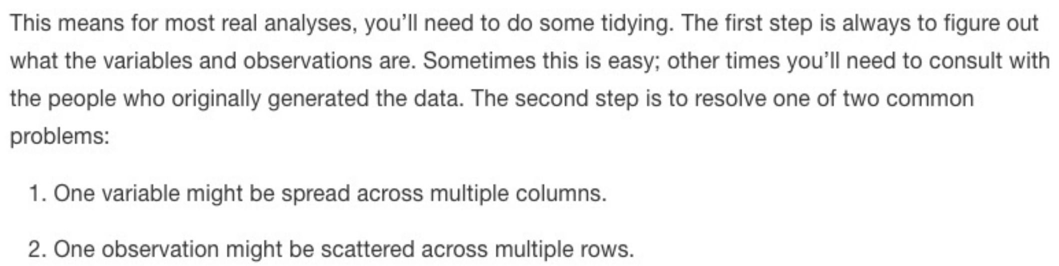
# Tidy Data



There are three interrelated rules which make a dataset tidy:

1. Each variable must have its own column.
2. Each observation must have its own row.
3. Each value must have its own cell.

Figure 12.1 shows the rules visually.



This means for most real analyses, you'll need to do some tidying. The first step is always to figure out what the variables and observations are. Sometimes this is easy; other times you'll need to consult with the people who originally generated the data. The second step is to resolve one of two common problems:

1. One variable might be spread across multiple columns.

2. One observation might be scattered across multiple rows.

## Action Item:

Find examples in the Tara Oceans or TCGA data.

ESR1 is one variable but it has 2 columns.

LONGER

① T ~

| participant | at diagnosis<br>ESR1 | after treatment<br>ESR1 |
|---|---|---|
| AINF | 628 | 527 |
| ⋮ | ⋮ | ⋮ |

```
T %>%
pivot_longer(c("at diagnosis ESR1", "after treatment ESR1"),
             names_to = "measurement point",
             values_to = "expression"
```

tibble ~

| participant | at diagnosis | after treatment |
|---|---|---|
| | ESR1 | ESR1 |
| AINF | 628 | 527 |
| ⋮ | ⋮ | ⋮ |

⇓

| part. | measurement pt. | expression |
|---|---|---|
| AINF | at diagnosis ESR | 628 |
| AINF | after treatment | 527 |

② **WIDER** One obs. across many rows.

T2

| participant | gene | count |
|---|---|---|
| AINF | ESR1 | 628 |
| AINF | ANLN | 527 |

2 rows

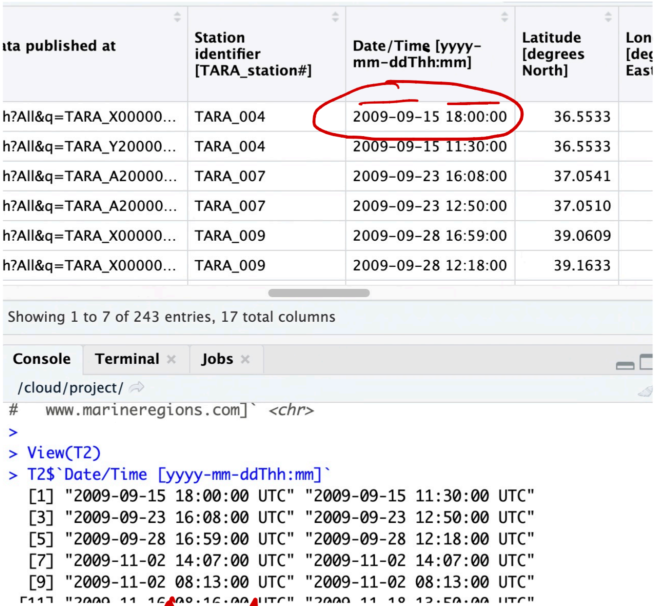
AINF IS ONE OBSERVATION (FOR WHICH WE MEASURE MANY VARIABLES).

```
T %>%
  pivot_wider(names_from = gene, values_from =
                                        count)
```

⇓

| parti | ESR1 | ANLN |
|---|---|---|
| AINF | 628 | 527. |

- separate - when a single variable has >1 pieces of information (values).



| ata published at | Station identifier [TARA_station#] | Date/Time [yyyy-mm-ddThh:mm] | Latitude [degrees North] | Lon [deg East |
|---|---|---|---|---|
| h?All&q=TARA_X00000... | TARA_004 | 2009-09-15 18:00:00 | 36.5533 | |
| h?All&q=TARA_Y20000... | TARA_004 | 2009-09-15 11:30:00 | 36.5533 | |
| h?All&q=TARA_A20000... | TARA_007 | 2009-09-23 16:08:00 | 37.0541 | |
| h?All&q=TARA_A20000... | TARA_007 | 2009-09-23 12:50:00 | 37.0510 | |
| h?All&q=TARA_X00000... | TARA_009 | 2009-09-28 16:59:00 | 39.0609 | |
| h?All&q=TARA_X00000... | TARA_009 | 2009-09-28 12:18:00 | 39.1633 | |

Showing 1 to 7 of 243 entries, 17 total columns

```
#    www.marineregions.com]` <chr>
>
> View(T2)
> T2$`Date/Time [yyyy-mm-ddThh:mm]`
  [1] "2009-09-15 18:00:00 UTC" "2009-09-15 11:30:00 UTC"
  [3] "2009-09-23 16:08:00 UTC" "2009-09-23 12:50:00 UTC"
  [5] "2009-09-28 16:59:00 UTC" "2009-09-28 12:18:00 UTC"
  [7] "2009-11-02 14:07:00 UTC" "2009-11-02 14:07:00 UTC"
  [9] "2009-11-02 08:13:00 UTC" "2009-11-02 08:13:00 UTC"
 [11] "2009-11-16 08:16:00 UTC" "2009-11-18 13:50:00 UTC"
```

?

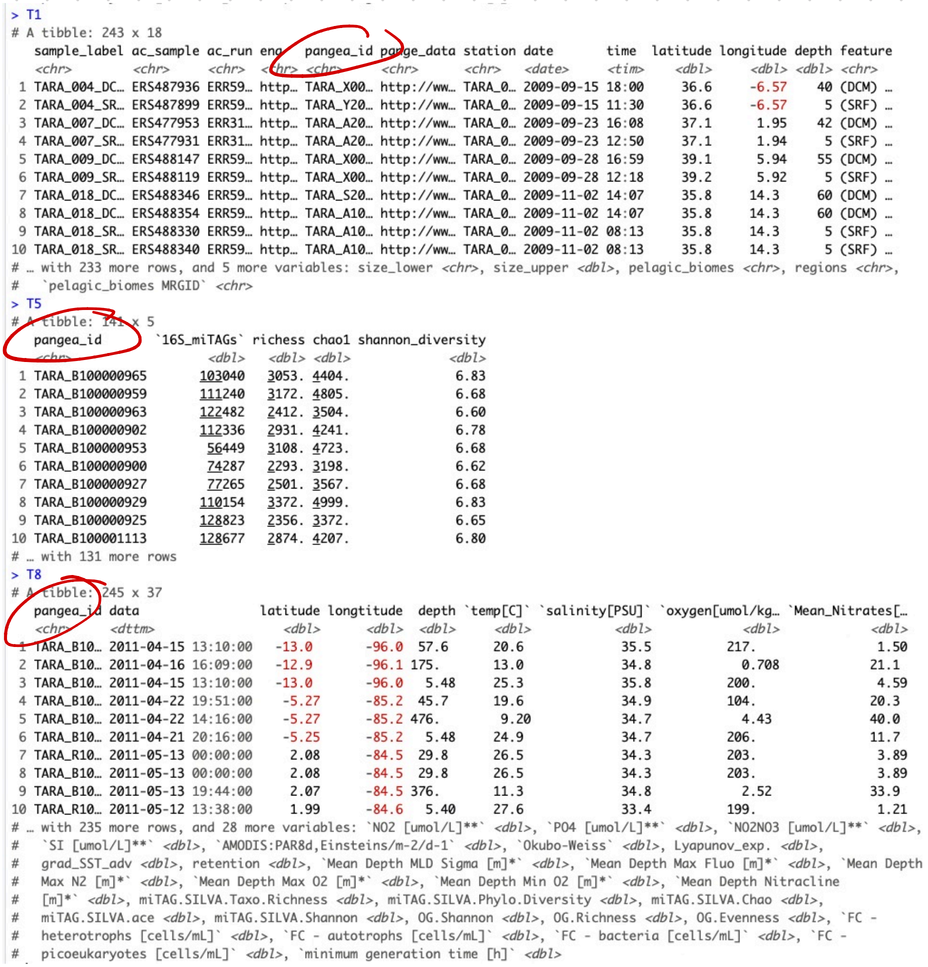
```
T1 %>%
   separate(`Date/Time...`, into = c("date", "time"),
                  sep = " ")
```

space

not optimal

| ... | date <chr> | time <chr> | ... |
|---|---|---|---|
| | "2009-09-15" | "18:00:00" | |

Tidy data should all be in the same tibble.



```
> T1
# A tibble: 243 x 18
   sample_label ac_sample ac_run eng… pangea_id pange_data station date       time  latitude longitude depth feature
   <chr>        <chr>     <chr>  <chr> <chr>    <chr>      <chr>   <date>     <tim>    <dbl>     <dbl> <dbl> <chr>
 1 TARA_004_DC… ERS487936 ERR59… http… TARA_X00… http://ww… TARA_0… 2009-09-15 18:00     36.6     -6.57    40 (DCM) …
 2 TARA_004_SR… ERS487899 ERR59… http… TARA_Y20… http://ww… TARA_0… 2009-09-15 11:30     36.6     -6.57     5 (SRF) …
 3 TARA_007_DC… ERS477953 ERR31… http… TARA_A20… http://ww… TARA_0… 2009-09-23 16:08     37.1      1.95    42 (DCM) …
 4 TARA_007_SR… ERS477931 ERR31… http… TARA_A20… http://ww… TARA_0… 2009-09-23 12:50     37.1      1.94     5 (SRF) …
 5 TARA_009_DC… ERS488147 ERR59… http… TARA_X00… http://ww… TARA_0… 2009-09-28 16:59     39.1      5.94    55 (DCM) …
 6 TARA_009_SR… ERS488119 ERR59… http… TARA_X00… http://ww… TARA_0… 2009-09-28 12:18     39.2      5.92     5 (SRF) …
 7 TARA_018_DC… ERS488346 ERR59… http… TARA_A10… http://ww… TARA_0… 2009-11-02 14:07     35.8     14.3     60 (DCM) …
 8 TARA_018_DC… ERS488354 ERR59… http… TARA_A10… http://ww… TARA_0… 2009-11-02 14:07     35.8     14.3     60 (DCM) …
 9 TARA_018_SR… ERS488330 ERR59… http… TARA_A10… http://ww… TARA_0… 2009-11-02 08:13     35.8     14.3      5 (SRF) …
10 TARA_018_SR… ERS488340 ERR59… http… TARA_A10… http://ww… TARA_0… 2009-11-02 08:13     35.8     14.3      5 (SRF) …
# … with 233 more rows, and 5 more variables: size_lower <chr>, size_upper <dbl>, pelagic_biomes <chr>, regions <chr>,
#   `pelagic_biomes MRGID` <chr>
> T5
# A tibble: 141 x 5
   pangea_id        `16S_miTAGs` richess chao1 shannon_diversity
   <chr>                   <dbl>   <dbl> <dbl>             <dbl>
 1 TARA_B100000965        103040   3053. 4404.              6.83
 2 TARA_B100000959        111240   3172. 4805.              6.68
 3 TARA_B100000963        122482   2412. 3504.              6.60
 4 TARA_B100000902        112336   2931. 4241.              6.78
 5 TARA_B100000953         56449   3108. 4723.              6.68
 6 TARA_B100000900         74287   2293. 3198.              6.62
 7 TARA_B100000927         77265   2501. 3567.              6.68
 8 TARA_B100000929        110154   3372. 4999.              6.83
 9 TARA_B100000925        128823   2356. 3372.              6.65
10 TARA_B100001113        128677   2874. 4207.              6.80
# … with 131 more rows
> T8
# A tibble: 245 x 37
   pangea_id data                latitude longtitude depth `temp[C]` `salinity[PSU]` `oxygen[umol/kg… `Mean_Nitrates[…
   <chr>     <dttm>                 <dbl>      <dbl> <dbl>     <dbl>           <dbl>            <dbl>            <dbl>
 1 TARA_B10… 2011-04-15 13:10:00   -13.0       -96.0  57.6      20.6            35.5          217.                1.50
 2 TARA_B10… 2011-04-16 16:09:00   -12.9       -96.1 175.       13.0            34.8            0.708            21.1
 3 TARA_B10… 2011-04-15 13:10:00   -13.0       -96.0   5.48     25.3            35.8          200.                4.59
 4 TARA_B10… 2011-04-22 19:51:00    -5.27      -85.2  45.7      19.6            34.9          104.               20.3
 5 TARA_B10… 2011-04-22 14:16:00    -5.27      -85.2 476.        9.20           34.7            4.43             40.0
 6 TARA_B10… 2011-04-21 20:16:00    -5.25      -85.2   5.48     24.9            34.7          206.               11.7
 7 TARA_R10… 2011-05-13 00:00:00     2.08      -84.5  29.8      26.5            34.3          203.                3.89
 8 TARA_B10… 2011-05-13 00:00:00     2.08      -84.5  29.8      26.5            34.3          203.                3.89
 9 TARA_B10… 2011-05-13 19:44:00     2.07      -84.5 376.       11.3            34.8            2.52             33.9
10 TARA_R10… 2011-05-12 13:38:00     1.99      -84.6   5.40     27.6            33.4          199.                1.21
# … with 235 more rows, and 28 more variables: `NO2 [umol/L]**` <dbl>, `PO4 [umol/L]**` <dbl>, `NO2NO3 [umol/L]**` <dbl>,
#   `SI [umol/L]**` <dbl>, `AMODIS:PAR8d,Einsteins/m-2/d-1` <dbl>, `Okubo-Weiss` <dbl>, Lyapunov_exp. <dbl>,
#   grad_SST_adv <dbl>, retention <dbl>, `Mean Depth MLD Sigma [m]*` <dbl>, `Mean Depth Max Fluo [m]*` <dbl>, `Mean Depth
#   Max N2 [m]*` <dbl>, `Mean Depth Max O2 [m]*` <dbl>, `Mean Depth Min O2 [m]*` <dbl>, `Mean Depth Nitracline
#   [m]*` <dbl>, miTAG.SILVA.Taxo.Richness <dbl>, miTAG.SILVA.Phylo.Diversity <dbl>, miTAG.SILVA.Chao <dbl>,
#   miTAG.SILVA.ace <dbl>, miTAG.SILVA.Shannon <dbl>, OG.Shannon <dbl>, OG.Richness <dbl>, OG.Evenness <dbl>, `FC -
#   heterotrophs [cells/mL]` <dbl>, `FC - autotrophs [cells/mL]` <dbl>, `FC - bacteria [cells/mL]` <dbl>, `FC -
#   picoeukaryotes [cells/mL]` <dbl>, `minimum generation time [h]` <dbl>
```

Quite straight forward to link this data.

Pangea_id is both a foreign & primary key. (Section 13.3 keys)

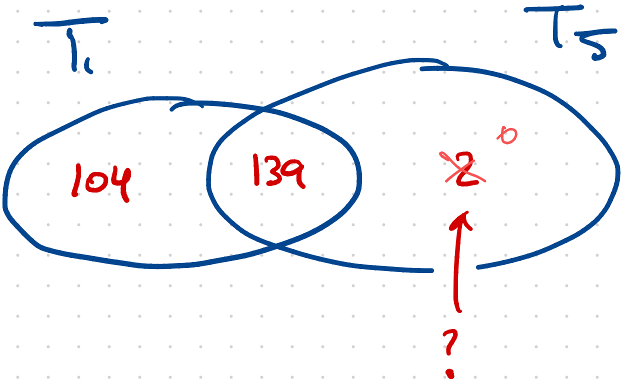
Start with tables $T_1$ & $T_5$.

$T_1$

| pangea_id | sample_label | ... |
|---|---|---|
| TARA_X00... | - - - | ... |
| ⋮ | ⋮ | ⋮ |

$T_5$

| pangea_id | 16S_miTAGs | ... |
|---|---|---|
| TARA_B1... | - - - | ... |
| ⋮ | ⋮ | ⋮ |



In general ...

$T_1$

| key | value | ... |
|---|---|---|
| T0 | 5 | -- |
| T1 | 7 | |
| T2 | 3 | |

$T_5$

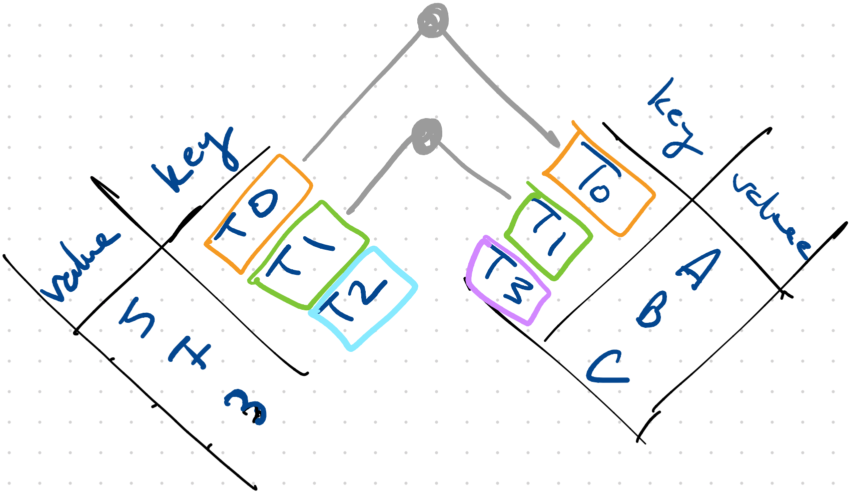
| key | value | ... |
|---|---|---|
| T0 | A | ... |
| T1 | B | |
| T3 | C | |

$T_1$

| key | value | ... |
|---|---|---|
| T0 | 5 | -- |
| T1 | 7 | |
| T2 | 3 | |

$T_5$

| key | value | .... |
|---|---|---|
| T0 | A | ... |
| T1 | B | |
| T3 | C | |



**Inner join:**

like an "and" operation

key must be in both tibbles.

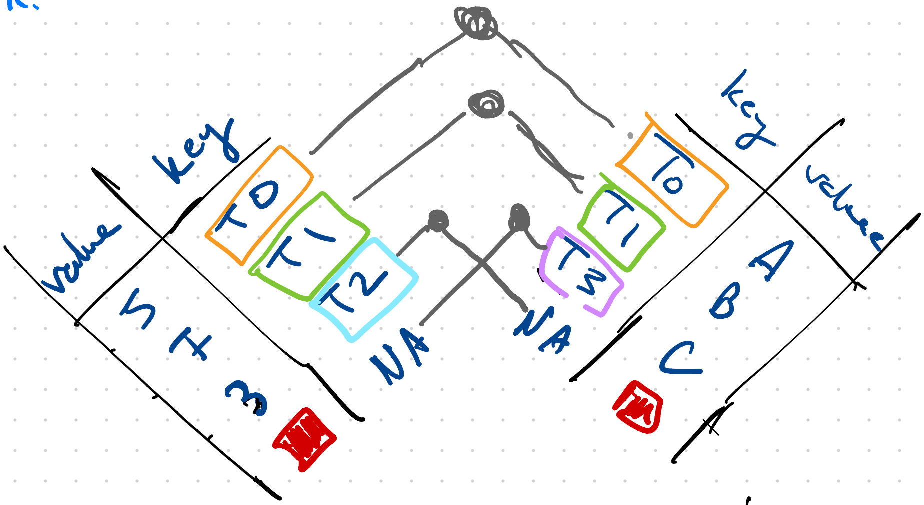
| key | value$_{T_1}$ | value$_{T_5}$ |
|---|---|---|
| T0 | 5 | A |
| T1 | 7 | B |

**Outer joins:** keeps observations (rows) in at least one of the tables.

3 types:

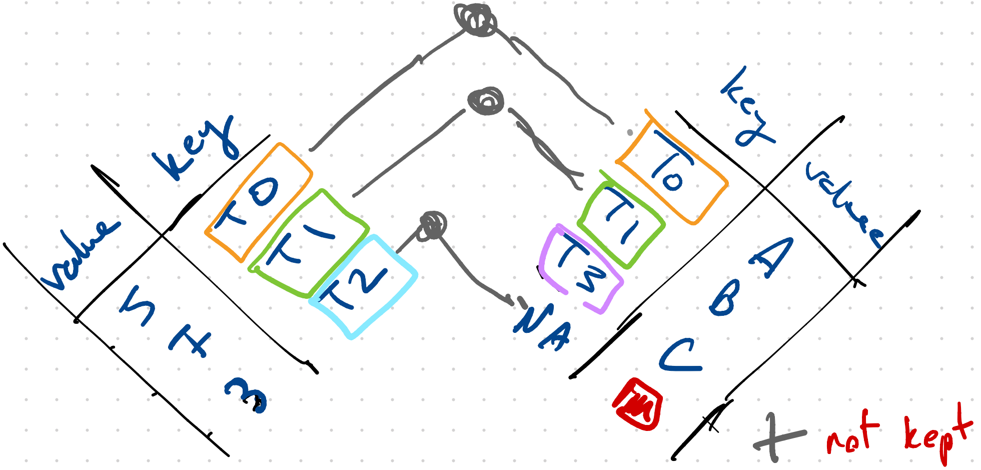
**Full join:** keeps all observations

sort of like an OR.



| key | value$_{T_1}$ | value $T_s$ |
|---|---|---|
| $T_0$ | 5 | A |
| $T_1$ | 7 | B |
| $T_2$ | 3 | NA |
| $T_3$ | NA | C |

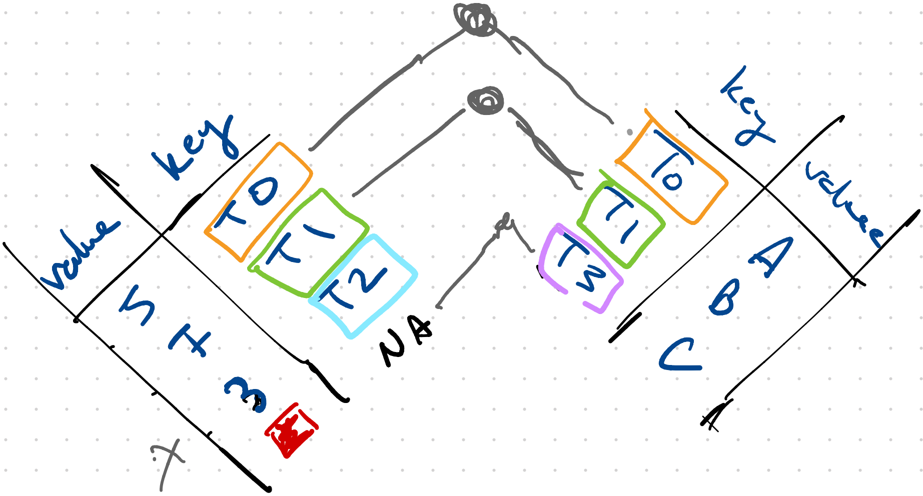
## Left join keep everything in first (left) tibble



| key | value$_{T_1}$ | value$_{T_5}$ |
|---|---|---|
| T0 | 5 | A |
| T1 | 7 | B |
| T2 | 3 | NA |

# Right join

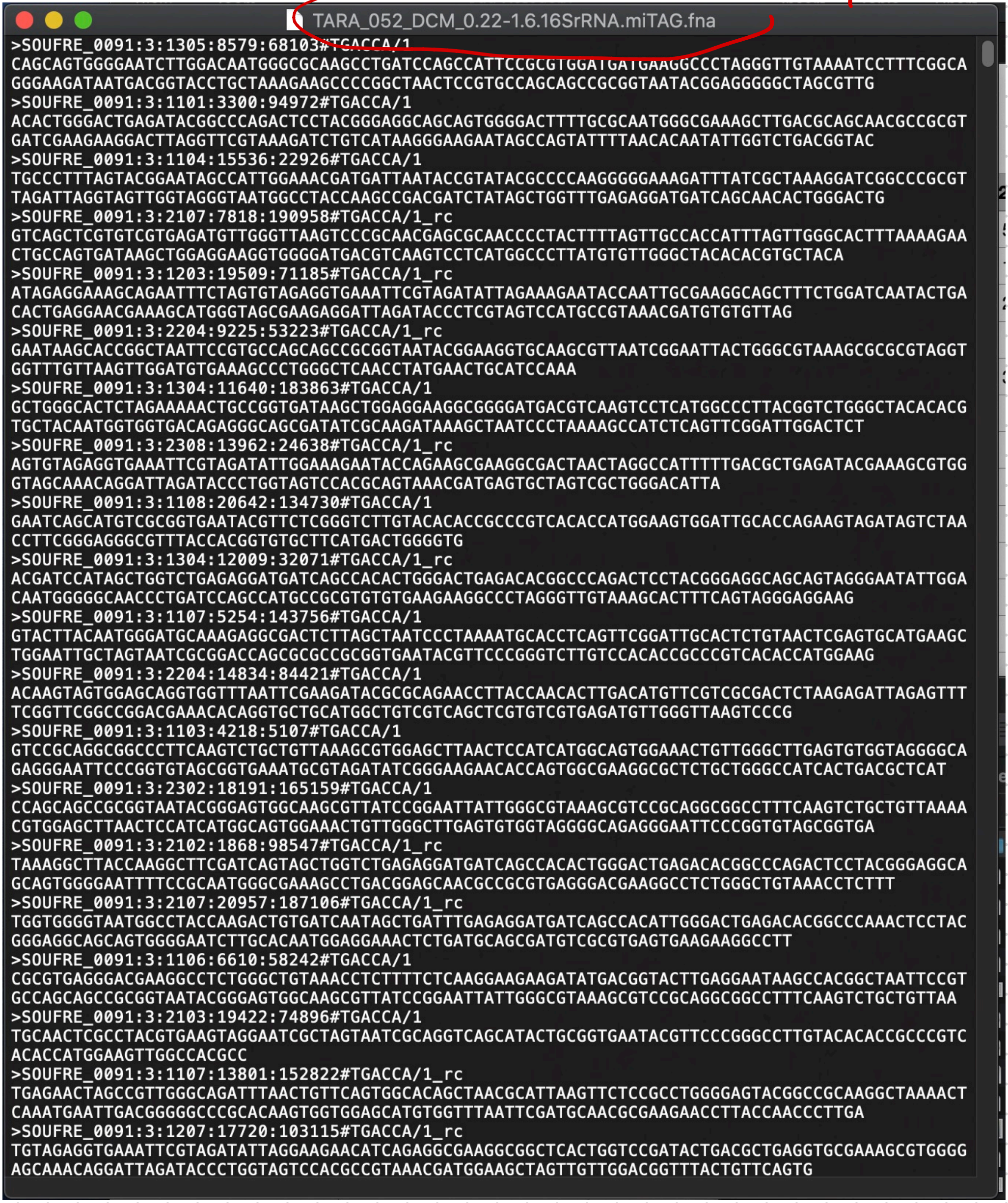
keep everything i
tibble



| key | value $_{T_1}$ | value $_{T_5}$ |
|---|---|---|
| T0 | 5 | A |
| T1 | 7 | B |
| T3 | NA | C |

16SRNA miTAG sequences : 500 Mb.

One sample file. What variable in T does this correspond to?



TARA_052_DCM_0.22-1.6.16SrRNA.miTAG.fna

```
>SOUFRE_0091:3:1305:8579:68103#TGACCA/1
CAGCAGTGGGGAATCTTGGACAATGGGCGCAAGCCTGATCCAGCCATTCCGCGTGGATGATGAAGGCCCTAGGGTTGTAAAATCCTTTCGGCA
GGGAAGATAATGACGGTACCTGCTAAAGAAGCCCCGGCTAACTCCGTGCCAGCAGCCGCGGTAATACGGAGGGGGCTAGCGTTG
>SOUFRE_0091:3:1101:3300:94972#TGACCA/1
ACACTGGGACTGAGATACGGCCCAGACTCCTACGGGAGGCAGCAGTGGGGACTTTTGCGCAATGGGCGAAAGCTTGACGCAGCAACGCCGCGT
GATCGAAGAAGGACTTAGGTTCGTAAAGATCTGTCATAAGGGAAGAATAGCCAGTATTTTAACACAATATTGGTCTGACGGTAC
>SOUFRE_0091:3:1104:15536:22926#TGACCA/1
TGCCCTTTAGTACGGAATAGCCATTGGAAACGATGATTAATACCGTATACGCCCCAAGGGGGAAAGATTTATCGCTAAAGGATCGGCCCGCGT
TAGATTAGGTAGTTGGTAGGGTAATGGCCTACCAAGCCGACGATCTATAGCTGGTTTGAGAGGATGATCAGCAACACTGGGACTG
>SOUFRE_0091:3:2107:7818:190958#TGACCA/1_rc
GTCAGCTCGTGTCGTGAGATGTTGGGTTAAGTCCCGCAACGAGCGCAACCCCTACTTTTAGTTGCCACCATTTAGTTGGGCACTTTAAAAGAA
CTGCCAGTGATAAGCTGGAGGAAGGTGGGGATGACGTCAAGTCCTCATGGCCCTTATGTGTTGGGCTACACACGTGCTACA
>SOUFRE_0091:3:1203:19509:71185#TGACCA/1_rc
ATAGAGGAAAGCAGAATTTCTAGTGTAGAGGTGAAATTCGTAGATATTAGAAAGAATACCAATTGCGAAGGCAGCTTTCTGGATCAATACTGA
CACTGAGGAACGAAAGCATGGGTAGCGAAGAGGATTAGATACCCTCGTAGTCCATGCCGTAAACGATGTGTGTTAG
>SOUFRE_0091:3:2204:9225:53223#TGACCA/1_rc
GAATAAGCACCGGCTAATTCCGTGCCAGCAGCCGCGGTAATACGGAAGGTGCAAGCGTTAATCGGAATTACTGGGCGTAAAGCGCGCGTAGGT
GGTTTGTTAAGTTGGATGTGAAAGCCCTGGGCTCAACCTATGAACTGCATCCAAA
>SOUFRE_0091:3:1304:11640:183863#TGACCA/1
GCTGGGCACTCTAGAAAAACTGCCGGTGATAAGCTGGAGGAAGGCGGGGATGACGTCAAGTCCTCATGGCCCTTACGGTCTGGGCTACACACG
TGCTACAATGGTGGTGACAGAGGGCAGCGATATCGCAAGATAAAGCTAATCCCTAAAAGCCATCTCAGTTCGGATTGGACTCT
>SOUFRE_0091:3:2308:13962:24638#TGACCA/1_rc
AGTGTAGAGGTGAAATTCGTAGATATTGGAAAGAATACCAGAAGCGAAGGCGACTAACTAGGCCATTTTTGACGCTGAGATACGAAAGCGTGG
GTAGCAAACAGGATTAGATACCCTGGTAGTCCACGCAGTAAACGATGAGTGCTAGTCGCTGGGACATTA
>SOUFRE_0091:3:1108:20642:134730#TGACCA/1
GAATCAGCATGTCGCGGTGAATACGTTCTCGGGTCTTGTACACACCGCCCGTCACACCATGGAAGTGGATTGCACCAGAAGTAGATAGTCTAA
CCTTCGGGAGGGCGTTTACCACGGTGTGCTTCATGACTGGGGTG
>SOUFRE_0091:3:1304:12009:32071#TGACCA/1_rc
ACGATCCATAGCTGGTCTGAGAGGATGATCAGCCACACTGGGACTGAGACACGGCCCAGACTCCTACGGGAGGCAGCAGTAGGGAATATTGGA
CAATGGGGGCAACCCTGATCCAGCCATGCCGCGTGTGTGAAGAAGGCCCTAGGGTTGTAAAGCACTTTCAGTAGGGAGGAAG
>SOUFRE_0091:3:1107:5254:143756#TGACCA/1
GTACTTACAATGGGATGCAAAGAGGCGACTCTTAGCTAATCCCTAAAATGCACCTCAGTTCGGATTGCACTCTGTAACTCGAGTGCATGAAGC
TGGAATTGCTAGTAATCGCGGACCAGCGCGCCGCGGTGAATACGTTCCCGGGTCTTGTCCACACCGCCCGTCACACCATGGAAG
>SOUFRE_0091:3:2204:14834:84421#TGACCA/1
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```

# Sample Variance

# of points

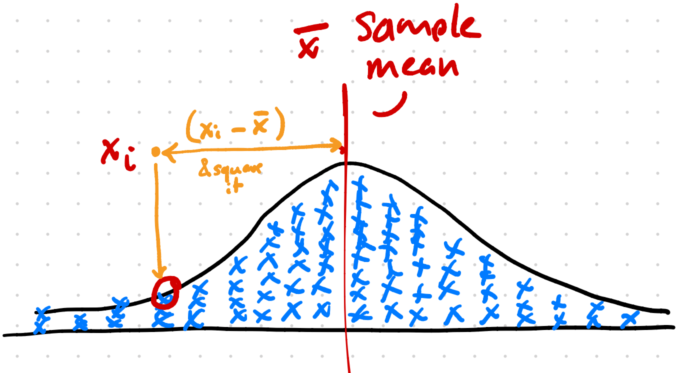
$$\sigma^2 = \frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n-1}$$

variance

Sigma means sum

↑ degrees of freedom

$(x_1 - \bar{x})^2 + (x_2 - \bar{x})^2 + \ldots + (x_n - \bar{x})^2$


$\bar{x}$ sample mean
$x_i$
$(x_i - \bar{x})$
& square it